Arnold Schwarzenegger
Governor

# QUANTIFYING THE POTENTIAL AIR QUALITY IMPACTS FROM ELECTRIC DEMAND EMBEDDED IN WATER MANAGEMENT CHOICES

PIER FINAL PROJECT REPORT

*Prepared For:*
**California Energy Commission**
*Public Interest Energy Research Program*

*Prepared By:*
**The Pacific Institute**

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# Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

What follows is the final report for the University of California Master Research Agreement contract, contract number 500-02-004, work authorization MRA 015-009, conducted by The Pacific Institute for Studies in Development, Environment, and Security in Oakland, California. The report is entitled *Quantifying the Potential Air Quality Impacts from Electric Demand Embedded in Water Management Choices*. This project contributes to the Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's Web site www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-4628.

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# Abstract

The Pacific Institute's Water to Air Models allow water managers to quantify the energy and air quality impacts of their management decisions. These impacts are increasingly relevant to water decision-making, as energy intensive options like seawater desalination and inter-basin transfers are weighed against options that are usually less energy intensive, such as use-efficiency, conjunctive use, or wastewater reclamation (recycling). The urban and agricultural models created in this project provide a flexible but consistent framework for quantifying the energy and air quality dimensions of water management decisions. They advance researchers' analytical capacities in a fully transparent way and support rational discussion and more detailed analysis of the economically and environmentally important water/energy/air quality nexus in coming years.

# Executive Summary

## Introduction

Bordered by the Pacific Ocean, and dotted with innumerable lakes, rivers, streams, reservoirs, canals, and aqueducts, California's water managers manipulate a complex array of natural and engineered systems to deliver water to where it is needed. A growing population of 36 million, as well as the State's agricultural and industrial sectors, uses more than a trillion gallons of water per year to maintain public health and a strong economy.

## Purpose

To meet this demand, California water managers must choose from various water sources and technologies used to acquire, treat, and transport water; and then treat, recycle, or dispose of the resulting wastewater. Water supply, treatment, distribution, use, and recycle/disposal options have energy consumption and air pollution impacts, and detailed information is needed to help managers determine the implications of their decisions.

Previous work by the Pacific Institute, the Natural Resources Defense Council (NRDC), and Bob Wilkinson of the University of California, Santa Barbara, shows that water management in California uses a significant amount of the state's energy. For example, a case study of the San Diego County Water Authority found that conserving 100,000 acre-feet of water per year would save enough energy to power 25% of residences in the City of San Diego for a year. A similar case study of the Westlands Water District found that the energy implications of fallowing 100,000 acres could be significant, depending on the final disposition of water no longer required to irrigate. Leaving the water currently used to irrigate in the Bay-Delta would save 71 million kilowatthours (kWh) of electricity per year; sending that water to San Diego via the State Water Project would increase electricity demand by 1.3 billion kWh per year.

Given this, the air quality implications of water management decisions are important, because energy production and use are often a source of air pollutants. Environmental Impact Reports (EIRs) prepared under the California Environmental Quality Act (CEQA) and Environmental Impact Statements (EISs) prepared under the U.S. National Environmental Policy Act (NEPA) rarely contain a thorough (if any) evaluation of the potential air pollution impacts of energy used in water projects. For example, the EIR/EIS for the water transfer from the Imperial Irrigation District to the San Diego County Water Authority did not discuss these impacts even though about 300 million kWh[1] of electric consumption or production will be involved each year.

[1] 2,110 kWh per acre-foot times 143,000 acre-feet per year, average, equals 300 million kWh.

**Project Objectives**

Objectives for this project involved preparation of an urban spreadsheet model and an agricultural spreadsheet model that water managers could use to assess energy use and air pollutant emissions that might result from their water management decisions.

**Project Outcomes**

A general methodology was developed, peer reviewed, and programmed; and a user manual and the two final models were developed, peer reviewed, and finalized.

The Pacific Institute's Urban and Agricultural Water to Air Models run in Excel 2002 and 2000 for Microsoft Windows. Both models and their user manual are available for download at no charge at www.pacinst.org. An electronic copy of the manual is provided at the end of this report, as Exhibit A. The Institute has announced availability of the manual in a press release and via our electronic newsletters. In addition, the California Urban Water Conservation Council (CUWCC) will be mailing printed copies of the user manual to its 400-plus membership.

The models permit users to specify the facilities in their water system from sources through consumptive use or disposal. The user specifies for each facility its annual water throughput, the amount of energy used at that facility, and the sources of energy for that facility. This can be done for two scenarios at a time. The models then compute energy use, energy intensity, and air emissions for each scenario, and the differences between scenarios.

**Recommendations**

Our recommendations for further work, based on reviewer feedback, are:

- The models should be used to develop statewide estimates of energy use and air emissions from current water management practices. These estimates are essential for policy analysis of energy supply and demand management in California. For example, what are the impacts on future electricity demand of more aggressive water conservation programs, more seawater desalination, and more reclaimed wastewater?

- Policies should also be implemented to ensure that energy and air quality impacts of water management decisions are accounted for in environmental assessments conducted in California. The state agency responsible for regulating CEQA could make this type of analysis (not necessarily using these models) mandatory for all water-related EIRs. In fact, it may be required under a strict interpretation of existing CEQA guidelines, but is not being done because writers and reviewers of EIRs have not realized there is a potentially significant water-to-energy-to-air connection.

- Training sessions for model use should be provided for water district and utility staff. Although the users manual adequately introduces users to the model and its basic uses, the models contain advanced capacities and enough flexibility that interested users would benefit from training sessions. The sessions could also serve as a venue for discussions about how to maximize the value of future versions of the models.

## Benefits to California

Significant economic and environmental benefits can be achieved cost-effectively in California's energy sector, through efficiency improvements in the state's water systems. Electric ratepayers pay for electricity directly and pay for air quality problems indirectly. Electricity demand reductions could result from improved water management, make lower retail prices more likely, and have a direct financial benefit for ratepayers. Reductions in air pollution could result from lower electric use in the water sector, and create health, aesthetic, and other benefits potentially worth billions of dollars annually.  This project lays the groundwork for capturing these public benefits.

## 1.0 Introduction

Bordered by the Pacific Ocean, and dotted with innumerable lakes, rivers, streams, reservoirs, canals, and aqueducts, California's water managers manipulate a complex array of natural and engineered systems to deliver water to where it is needed. A growing population of 36 million and the state's agricultural and industrial sectors use more than a trillion gallons of water per year to maintain public health and a strong economy.

To meet this demand, California water managers must choose from various water sources and technologies used to acquire, treat, and transport water; and then treat, recycle, or dispose of the resulting wastewater. Water supply, treatment, distribution, use, and recycle/disposal options have energy consumption and air pollution impacts, and detailed information is needed to help managers determine the implications of their decisions.

The Pacific Institute (PI) recently worked with the National Resource Defense Council (NRDC) to evaluate the energy used in water management (Wolff et al. 2004) based on methods pioneered by Bob Wilkinson of the University of California, Santa Barbara (Wilkinson 2000). The 2004 NRDC/PI report *Energy Down the Drain: The Hidden Costs of California's Water Supply* (on which Bob Wilkinson served as an advisor) includes case studies of San Diego County, the Westlands Water District in Central California, and the Columbia Basin Project in the Pacific Northwest. The report is available at no charge from www.pacinst.org.

Wilkinson (2000) and previous researchers had identified the water sector as a large users of electricity and other forms of energy in California. For example:

- The State Water Project is the largest single user of electricity in California, using 2%–3% of all electricity consumed in the state.
- The amount of energy used to deliver water from Northern California to Southern California households over the Tehachapi Mountains (the highest lift of any water system in the world) is equal to about 1/3 of the average electric household use that takes place within these homes.
- Ninety percent of all electricity used on farms in California is devoted to pumping.

*Energy Down the Drain* found that energy use in urban water management in California is even higher than previously recognized, primarily because energy used during customer use of water (e.g., for heating water) is often at least as large as energy used to extract, transport, treat, distribute, collect, and dispose of water and wastewater properly. For example, the San Diego County Case Study found that the equivalent[2] of about 7,000 kilowatthours (kWh) of electricity are used along with each acre-foot of water used there, with more than half of that energy use taking place on the customer side of the water meter but prior to wastewater discharge. To put this in context, conserving 100,000 acre-feet of water per year would save enough energy to power 25% of residences in the City of San Diego for a year.

*Energy Down the Drain* also found that the energy implications of land-fallowing[3] decisions (dry year or permanent) could be significant, depending on the final disposition of water no longer required to irrigate. If the water is sent to distant urban areas, energy use could be much larger than it is currently. If it were left in the source ecosystem (e.g., in the Bay-Delta for the State Water Project or the U.S. Central Valley Project), energy use could be much smaller than at present. For example, fallowing 100,000 acres in the Westlands Water District could reduce electricity use by 71 million kWh per year, or increase it by 1,300 million (1.3 billion) kWh per year, depending on the ultimate disposition of water that is currently used to irrigate these acres. Even when the water is kept within the irrigation district that fallowed land, the energy implications of different water use patterns can be significant, because having more water per acre of land can change crop patterns, irrigation practices, and energy used to cultivate and harvest crops.

Given this, the air quality implications of water management decisions may be substantial, since energy production and use is often a significant source of air pollutants. Environmental Impact Reports (EIRs) prepared under California Environmental Quality Act (CEQA) and Environmental Impact Statements (EISs) prepared under the National Environmental Policy Act (NEPA) rarely contain a thorough (or any) evaluation of the potential air pollution impacts of energy used in water projects. For example, the EIR/EIS for the water transfer from the Imperial Irrigation District to the San Diego County Water Authority did not discuss these impacts, even though about 300 million kWh of electric consumption or production will be involved each year.

Consequently, we prepared two spreadsheet models usable by water managers to assess both the energy and air pollutant emissions that might result from their water management decisions. One was for urban water managers; the other was for managers of agricultural irrigation water. The goals were:

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[2] All of this energy use is not electricity; hence the word "equivalent." Other types of energy use (e.g., natural gas for water heating) are converted to equivalent kWh of electricity using heat rates (British thermal units required to generate each kWh) appropriate for power plants that use each type of fuel.

[3] *Land fallowing* means taking land out of agricultural production, temporarily or permanently.

- to develop a general methodology for quantifying air pollutant emissions from energy consumption that results from various water management choices, and
- to make the methodology available in the public domain, with full documentation and several illustrations of the method.

The remainder of this report is organized as follows. Section 2 presents the project approach, Section 3 describes project outcomes, and Section 4 discusses conclusions and recommendations. The user manual for the models is provided in Appendix A. The manual is published separately and was mailed to water district and utility managers throughout the state. The manual and models are also available for download at no charge from www.pacinst.org.

## 2.0 Project Approach

The project approach consisted of:

- collecting information through a literature search on air emissions from energy generation,
- enhancement of existing models,
- consultation with experts in the field, and
- finalization of the models and user manual.

## 3.0 Project Outcomes

The models were created, reviewed, and documented in the user manual (see Appendix A). The models allow users to compare the energy use and air pollutant emissions of two water management scenarios in either an urban or agricultural context. The output sheet within the model shows estimated annual energy use and emissions for both scenarios, as well as the annual differences between the scenarios (Scenario Two minus Scenario One). The user manual describes how users create scenarios.

The goals of developing a general methodology and widely disseminating the models and users manual were achieved. The user manual and models were announced in the PI's printed and electronic newsletter and appropriate electronic mailing lists. Printed copies of the user manual were mailed to water districts in California by the CUWCC.

Some additional information on outcomes by project task is probably useful, to understand the context within which the models were created and will likely be used. First, we developed an understanding of the literature on air emissions from energy consumed in California. We began by having discussions with the California Air Resources Board (CARB) and California Energy Commission staff listed in the acknowledgements. We also searched the Web and the University of California Berkeley libraries for relevant documents, and reviewed them.

Emissions from energy use vary by fuel type, type of equipment and its age, percent of full load capacity for each piece of equipment being utilized at any particular time (e.g., emissions per unit of electricity produced are higher when a plant is operating at less than 100% capacity), and other factors. Emissions per unit of electricity produced at a centralized power plant are also not the same as emissions per unit of electricity delivered to customers, because line losses of 7.5% or more occur.

We found that time-varying air emissions data are available for each power plant in California and the western region, but these data have rarely been aggregated across all plants of one type (e.g., natural gas), across all times in one year, or across all the power sources that serve each geographic area (e.g., the service area of Pacific Gas and Electric). The computational effort required to develop such aggregates was beyond this project's resources. Furthermore, some of the information found was not useful. For example, information on the emissions of off-road vehicles (e.g., farm tractors) are available, but these data contain some details that were too unwieldy for a usable first version of the model (e.g., emissions by engine size category).

Fortunately, we were able to obtain from the CARB credible average emissions data for each energy type (e.g., natural gas), and the actual mix of energy sources in 2004 (referred to as the "California Grid Mix" in the model documentation). Using these data, our models are able to accommodate different mixes of energy sources in different parts of the state or for each facility, as explained further below. But all mixes of energy sources are ultimately based on statewide average emissions for each source (e.g., natural gas), rather than the particular emissions for power plants near the user.

Appendix B of the user manual (see Appendix A of this report) documents the sources and calculations behind the air emissions factors used in the models. The emissions factors themselves are listed on the "assumptions" spreadsheet within the models. For example, the emissions factors used for the California Grid Mix are listed in Table 1.

In some instances (discussed in more detail in Appendix B of the users manual), emissions factors were not available for all categories of pollutants from all sources of emissions. Consequently, we made conservative professional judgments about the most reasonable emissions inputs to use in the models. But model users are cautioned that the judgments may not be applicable in all cases.

**Table 1. Emissions factors used for the California grid mix**

| Pollutant | Emissions Factor (grams per equivalent kWh) |
|---|---|
| Total organic gases or compounds | 0.016135 |
| Reactive organic gases or compounds | 0.01472 |
| Carbon monoxide | 0.21105 |
| Nitrogen oxides | 0.10307 |
| Sulfur oxides | 0.00982 |
| Total particulates | 0.02157 |
| Particulates < 10 microns | 0.01816 |
| Carbon dioxide | 471.00000 |

In addition to obtaining emissions factors, we used Visual Basic programming within Excel to extend the models used in *Energy Down the Drain* (Wolff et al. 2004). The previous models were sets of linked spreadsheets. Consequently, they required a high level of user knowledge to use properly. Their primary contribution was as a consistent accounting framework for the energy used to manage water, starting with sources of raw water and continuing through all steps in the water use-disposal supply chain (e.g., sources and bulk conveyance, treatment, distribution, customer use, and wastewater disposal).

The previous models calculated equivalent kWh in total, and per unit, for water delivered to customers. This calculation involves adjustments for losses in water as it moves through the supply chain (e.g., evaporation from canals, leakage in pipes, and consumptive uses by customers), which reduces the quantity of wastewater requiring treatment. The previous models also performed these calculations using the concept of "equivalent" kWh used, rather than actual kWh of electricity used. An equivalent kWh is the electricity that could be generated and delivered to a customer if the fuel they are using directly (e.g., natural gas used to heat water on the customers premises) were converted to electricity prior to use. This measure is necessary in order to provide a single summary number when not all energy is in the form of electricity. For example, some pumping actually uses electricity and other pumping is accomplished using fuels directly, without producing electricity.

The models created in this project extended the previous models in the following ways:

- **Created a Visual Basic interface and user manual, so that anyone with minimal training can perform this type of analysis.** For example, the new models include error messages that prevent meaningless outputs from being created if some of the more common types of input errors occur. Similarly, the new models include conversion calculators between commonly used units of measure. These features also reduce the likelihood of erroneous outputs.
- **Added an air emissions calculation.** This enhancement includes the capacity to specify different sources of energy for each facility input to the model (e.g., a water treatment plant). Nine sources of energy can be specified in the urban model; ten in the agricultural model. The models are very flexible in the energy-to-air relationships available to users, because the models allow users to create eight mixes of these sources.
- **Formatted the input and output sheets to automatically calculate the differences in energy use and air emissions between two water management scenarios.** The previous models evaluated only one scenario at a time. Comparisons required the user to run the model twice and compare outputs manually.

The enhanced models do not have all the features some users might like, in order to keep the models manageable for unsophisticated users. For example, one model extension we initially proposed was to adjust the energy embedded in water to "normalize it" to a benchmark level of quality. Colorado River water is saltier than water from the Bay-Delta. A normalized comparison would require that one calculate the energy required to remove salts from Colorado River water until it is the same quality as Bay-Delta water. In the end, we chose to treat all potable water the same, even though salt and other constituents vary among potable water sources. In practice, water utilities usually address variation in water quality among their raw water sources through blending, rather than by treatment of lower quality water. Forcing all raw water sources input to the model to have an associated energy use that reflects treatment to a quality standard would not represent actual practice. The model does allow users to report the actual or projected energy use of treating one or more raw water sources to one or more water quality standards; which in turn allows the disparity in quality concern to be addressed when a model user feels that doing so is necessary. But to include a required adjustment to normalize all differences in raw water quality, as originally envisioned, would have created confusion or frustration for model users.

All models have limitations. It is important to recognize what these models do not do. They do not evaluate marginal energy use or air emissions. All energy use and air emissions factors represent averages, not changes at the margin. For example, natural gas emissions are from average existing natural gas power plants. The models would probably overstate air emissions from new water facilities that rely on new natural gas power plants. The models also do not evaluate the impacts of air emissions. The health or environmental impacts of emissions may depend on where they occur. Finally, the models do not evaluate the indirect energy and air emissions differences between scenarios. For example, nuclear power plants are assumed to have zero air emissions, which is correct for their direct emissions. But construction of nuclear plants, like all construction, involves energy use and emissions. Indirect energy use and emissions are those embedded in the capital facilities themselves. Readers interested in indirect energy use and emissions in the water sector should look at the work of Arpad Horvath (forthcoming), funded in part by the California Energy Commission.

We asked experts in this area and some water district staff to provide feedback on the first drafts of the models. Their most substantive comments are listed below. Our response to each is provided in italics after each comment.

- An energy unit conversion calculator should be added (only a water unit calculator existed at that time). *We added one*.
- Could the overall unit of energy measure in the model (equivalent kWh) be decomposed in the model outputs into actual electricity and other fuels used directly (e.g., diesel fuel used in direct drive pumps)? *We added this decomposition to the model output sheets.*
- The models' limitations should be spelled out more fully. *We added text that clarified the models' limitations.*
- Some of the presentation features should be changed to make the models visually simpler and more intuitive to use. *We made all of the suggested changes. For example, the draft models described facilities that use energy as "nodes" and lists of many facilities of the same type (e.g., groundwater sources) as "sub-nodes." These were relabeled "facilities" in the final models.*

- Could users input custom emissions factors (e.g., grams of nitrogen oxides per kWh) to better reflect their particular circumstances? *We could not address this concern with the resources available. Because the model allows up to eight mixes of energy sources to be specified for every facility that is modeled, each containing up to nine sources of energy, the programming required to integrate custom inputs in a user-friendly way was too time consuming for our budget. It is possible, however, to input alternative emissions factors by unlocking the assumptions spreadsheet and over-writing the factors that exist now. We do not recommend doing this, because it could lead to corruption of the model code or the existence of multiple versions of the models, all labeled "Version 1," but actually different.*
- Could the model have the capability for three levels of output: normal, minimum output, maximum output? This would convey a better understanding of the likely ranges of energy and air quality impacts as a function of inputs. *We did not try to program this capability in the models. It would be quite difficult to do and would perhaps be misleading. The energy default values in the models now do not necessarily reflect normal or average conditions. They provide a sense of scale based on limited data from a few locations that are documented in Appendix A of the user manual (see Appendix A of this report). We don't have enough data to estimate minimums or maximums for these values. The emissions factors in the models do represent averages, but again, we do not have sufficient data to estimate minimum or maximum values for each category of emissions.*
- Can the models distinguish more among types of sewage treatment, which have widely varying energy and gaseous emissions requirements? *The models allow users to list up to 20 wastewater treatment plants and their energy use and energy sources. Therefore, this concern can be addressed within the existing model structure.*
- Could the models include an economic capability to allow one to integrate the financial consequences of energy and air quality impacts with other cost factors? *Yes, this would be a very powerful model enhancement. We stated in our grant proposal that the first version of the model would not include an economic layer, because it was too complex and costly for a first effort. However, future versions could and should include such capabilities.*
- Could the energy and air emissions from agriculture be expressed in terms of caloric output, or weight, or dollar value of crops grown using a particular amount of water? *These types of calculations are scientifically interesting and potentially policy-relevant, but would dramatically increase the input data requirements, complexity of calculations, and presentation of results. Furthermore, agricultural water district managers are well aware of the water required for each ton of commodity (e.g., potatoes) and the per-acre yields of these commodities. It would be fairly easy for them to calculate from our model output and these numbers the energy or air emissions per ton of commodity produced. If that were done and found to be useful, a focused extension of the agricultural model along these lines could be prepared in a later model version.*

## 4.0 Conclusions and Recommendations

The feedback received during peer review supports some conclusions and recommendations about future work for the California Energy Commission, the Pacific Institute, or other parties interested in the water-energy-air quality nexus.

Most important, the model should be used to develop statewide estimates of energy use and air emissions from current water management practices. We know energy use and air emissions from water management are significant, based on case studies in parts of the state, but have not performed a comprehensive statewide assessment. It might be possible to develop statewide estimates using 5–10 "representative" urban and agricultural water systems in California. These estimates are important for policy analyses of energy demand management in California. For example, policy decisions would be better informed if policy makers had more information regarding the impacts on future electricity demand from: more aggressive water conservation programs, more seawater desalination, more reclaimed wastewater, more agriculture-to-urban water transfers, more efficient on-farm irrigation systems, less leakage from irrigation water delivery canals, and other water management issues.

Second, policies should also be implemented to ensure that energy and air quality impacts of water management decisions are accounted for in environmental assessments conducted in California. These impacts are often not addressed—even in major water management decisions such as the water transfer from the Imperial Irrigation District to the San Diego County Water Authority that was discussed earlier. The state agency responsible for regulating CEQA could make this type of analysis mandatory for all water-related EIRs (although not necessarily using these models).

Third, the models have enough flexibility that interested users would benefit from training sessions. These sessions could be coordinated through and perhaps sponsored by existing organizations (e.g. the CUWCC, or the American Water Works Association). For example, participants could be walked through the examples in the users manual while sitting at computer terminals, then after a break, develop their own scenarios for comparison in working groups based on data they would be asked to bring to the workshop.

Finally, the models themselves could be expanded to add even more flexibility. Some useful extensions would be:

- User-specified air emissions factors, which would greatly strengthen the role of the models as project-level environmental assessment tools.
- An economic "layer" that would allow users to estimate the capital and energy cost impacts they directly bear in alternative water management scenarios, and the health or environmental cost impacts of air emissions borne by society. The capital and energy cost model enhancement would be very straightforward. The health and environmental costs would be more complicated, and have much larger uncertainty in costs, but would nonetheless be useful, because it would allow users to obtain ballpark cost estimates as a starting point for discussion.

- Sub-spreadsheets that would allow one to break facilities down into their component energy using parts (e.g., capacity to list unit processes in a water treatment plant). In the current models, these details need to be addressed by hand outside the model.
- Additional revisions identified by users of Version 1, either determined by a survey of users 6–12 months from now, or perhaps during training sessions for utility staff.

Significant economic and environmental benefits can be achieved cost-effectively in California's energy sector, through efficiency improvements in the state's water systems.

Ratepayers pay for electricity directly and pay for air quality problems indirectly. Electric demand reductions could result from improved water management, make lower retail prices more likely, and provide a direct financial benefit for ratepayers. Reductions in air pollution could result from lower energy use in the water sector, and create health, aesthetic, and other benefits. There are numerous studies of these benefits that demonstrate they are financially significant in California. This project was not designed to directly quantify those benefits, but it lays the groundwork for eventually doing so. Implementation of the recommendations above will ultimately lead to economic, environmental, and health benefits for Californians.

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## 6.0 Glossary

| | |
|---|---|
| CARB | California Air Resources Board |
| CEQA | California Environmental Quality Act |
| CIEE | California Institute for Energy Efficiency |
| CUWCC | California Urban Water Conservation Council |
| EIR | Environmental Impact Report |
| EIS | Environmental Impact Statement |
| KWh | kilowatt hours; that is, 1,000 watt-hours |
| NEPA | National Environmental Policy Act |
| NRDC | Natural Resources Defense Council |
| PI | Pacific Institute |
| PIER | Public Interest Energy Research |

# Appendix A

# Pacific Institute Water to Air Models User Manual

PACIFIC INSTITUTE

# User Manual

## for the Pacific Institute Water to Air Models

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# **User Manual** for the Pacific Institute Water to Air Models

(Version 1, October 2004)

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and Maggie Winslow, Ph.D., Air Quality Specialist

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## Legal Notice

# PREFACE

The Pacific Institute Water to Air Models allow water managers to quantify the energy and air quality impacts of their management decisions. These impacts are increasingly relevant to water decision-making, as energy-intensive options like seawater desalination and inter-basin transfers are weighed against less energy-intensive options such as conservation, use-efficiency, conjunctive use, or reclaimed wastewater. The urban and agricultural models documented in this manual provide a flexible but consistent framework for quantifying the energy and air quality dimensions of water management decisions. They advance our analytical capacities in a fully transparent way and support rational discussion and more detailed analysis of the economically and environmentally important water/energy/air quality “nexus”.

The models permit users to specify the facilities in their water system from sources through consumptive use or disposal. For each facility the user specifies its annual water throughput, the amount of energy used at that facility, and the sources of energy for that facility. This can be done for two scenarios at a time. The model then computes energy use, energy intensity, and air emissions for each scenario, and the difference between scenarios.

## Why Were These Models Created?

The Pacific Institute (PI) recently worked with the Natural Resources Defense Council (NRDC) to evaluate the energy used in water management (Wolff, et.al., 2004) based on methods pioneered by Bob Wilkinson of the University of California, Santa Barbara (Wilkinson, 2000). The NRDC/PI report—which Bob Wilkinson served as an advisor on—includes case studies of San Diego County, the Westlands Water District in Central California, and the Columbia Basin Project in the Pacific Northwest. The report is available at no charge from **www.pacinst.org/publications**.

One of the conclusions of that work was that energy use in urban water management in California is even more significant than previously recognized, primarily because energy used during customer use of water (e.g., for heating water) is often at least as large as energy used to extract, transport, treat, distribute, collect, and dispose of water and wastewater properly. For example, the San Diego County case study found that the equivalent of about 7,000 kilowatt hours (Kwh) of electricity are used for each acre-foot of water used there, with more than half of that energy use taking place on the customer side of the water meter but prior to wastewater discharge. To put this in context, conserving 100,000 acre-feet of water per year would save enough energy to power 25% of residences in the City of San Diego for a year.

The work also found that the energy implications of land fallowing decisions (dry year or permanent) could be significant, depending on the final disposition of water no longer required to irrigate. If the water were left in the source ecosystem (e.g., in the Bay-Delta for the State Water Project or the US Central Valley Project), energy use could be much smaller than at present; if sent to distant urban areas, energy use could be much larger than at present. For example, fallowing 100,000 acres in the Westlands Water District could reduce electricity use by 71 million kwh per year, or increase it by 1,300 million (1.3 billion) kwh per year. Even when kept within the irrigation district that fallowed land, the energy implications of different water use patterns can be significant because having more water per acre of land still cropped can change crop patterns, irrigation practices, and energy used to cultivate and harvest crops.

Given this, the air quality implications of water management decisions may be significant, since energy production and use is often a substantial source of air pollutants. Environmental Impact Reports (EIRs) prepared under the California Environmental Quality Act (CEQA) and Environmental Impact Statements (EISs) prepared under the US National Environmental Policy Act (NEPA) rarely contain a thorough (or any) evaluation of the potential air pollution impacts of energy used in water projects. For example, the Environmental Impact Report/Environmental Impact Statement (EIR/EIS) for the water transfer from the Imperial Irrigation District to the San Diego County Water Authority did not discuss these impacts even though about 300 million (2,110 kwh per acre-foot times 143,000 acre-foot per year, average) kwh of electric consumption or foregone hydroelectric production will be involved each year.

Consequently, the Institute decided to prepare two spreadsheet models usable by water managers to assess both the energy and air pollutant emissions that might result from their water management decisions. One is for urban water managers; the other is for managers of agricultural irrigation water.

## How Can the Models Help Me?

Both models allow comparison of the energy use and air pollutant emissions of two water management scenarios. The output sheet within the model shows estimated annual energy use and emissions for both scenarios, and the annual differences between the scenarios (Scenario Two minus Scenario One). Users create scenarios as described later in this manual.

The model outputs may be suitable for inclusion in environmental assessments: for example, program and project level EIRs and EISs. They are probably better suited for evaluation of programmatic alternatives than for evaluation of detailed project proposals and their alternatives. The key determinant of suitability for air quality emissions estimates is whether the emissions factors in the model fairly represent the specific situation being modeled. We've designed the models to be as transparent as possible. All calculations, for example, take place in the spreadsheet marked "engine"; and assumptions are shown in the spreadsheet marked "assumptions." Everything in the model is visible to the viewer, although most cells have been locked to prevent accidental changes that would corrupt the output. (The default energy use values in the "Start" and "Facility" spreadsheets are not locked because doing so would interfere with the visual basic code.)

If the models are used in EIRs or EISs, they can be included in their entirety as appendices so that reviewers can critique the assumptions and methods used. Therefore, at minimum, the models provide a useful and uniform starting point for analysis of the air quality impacts of water management decisions.

It is also important to recognize what the models do not do. They do not evaluate marginal energy use or air emissions. All energy use and air emissions factors represent averages, not changes at the margin. For example, natural gas emissions are from average existing natural gas power plants. The models would probably overstate air emissions from new water facilities that rely on new natural gas power plants. The models also do not evaluate the impacts of air emissions. The health or environmental impacts of emissions may depend on where they occur. Finally, the models do not evaluate the indirect energy and air emissions differences between scenarios. For example, nuclear power plants are assumed to have zero air emissions, which is correct for their direct emissions. But construction of nuclear plants, like all construction, involves energy use and emissions. Indirect energy use and emissions are those embedded in the capital facilities themselves. Readers interested in indirect energy use and emissions in the water sector should look at the work of Horvath (2004), funded in part by the California Energy Commission.

## Where Do I Get the Models?

The models are being provided free of charge by the Institute under a grant from the California Energy Commission Public Interest Energy Research (PIER)

Program. They can be downloaded from **www.pacinst.org/resources/water_to_air_models**. They run in Excel Versions 2002 and 2000. The models documented in this manual are labeled Version 1. If other versions are subsequently made available, an updated user manual will be provided at that time.

## What Are the Model Inputs and Outputs?

Before trying to run the models it may be helpful for users to understand and see examples of typical model inputs and outputs. We provide two examples—one urban and one agricultural—below. *You can also skip the examples and go directly to the section titled "How to Use the Models" that follows the examples.*

Both models require users to list the "facilities" at which energy is used in their water supply-use-disposal chain. For example, potable water treatment plants, distribution booster stations, types of end uses (e.g., clothes washing), and wastewater treatment plants are facilities. Facilities outside a water manager's jurisdiction might be aggregated together into a single facility in the model. For example, water delivered by the State Water Project to a user located in Southern California will often be listed as a single facility labeled "State Water Project" within the "Imported Water" input spreadsheet.

Both models require users to list the amount of water that flows through each facility in acre-feet per year.

Both models allow users to specify the amount of energy used at each facility in total over a year, or to use a default energy factor per acre-foot in some cases. Default values are not always available, but are provided for the most common types of facilities so that users can experiment with the model even if they have little site-specific information. Users be warned: default values may be inaccurate in your setting. Data sources for default values used in the models, and other relevant information that might help users estimate their energy use at facilities, are provided in Appendix A.

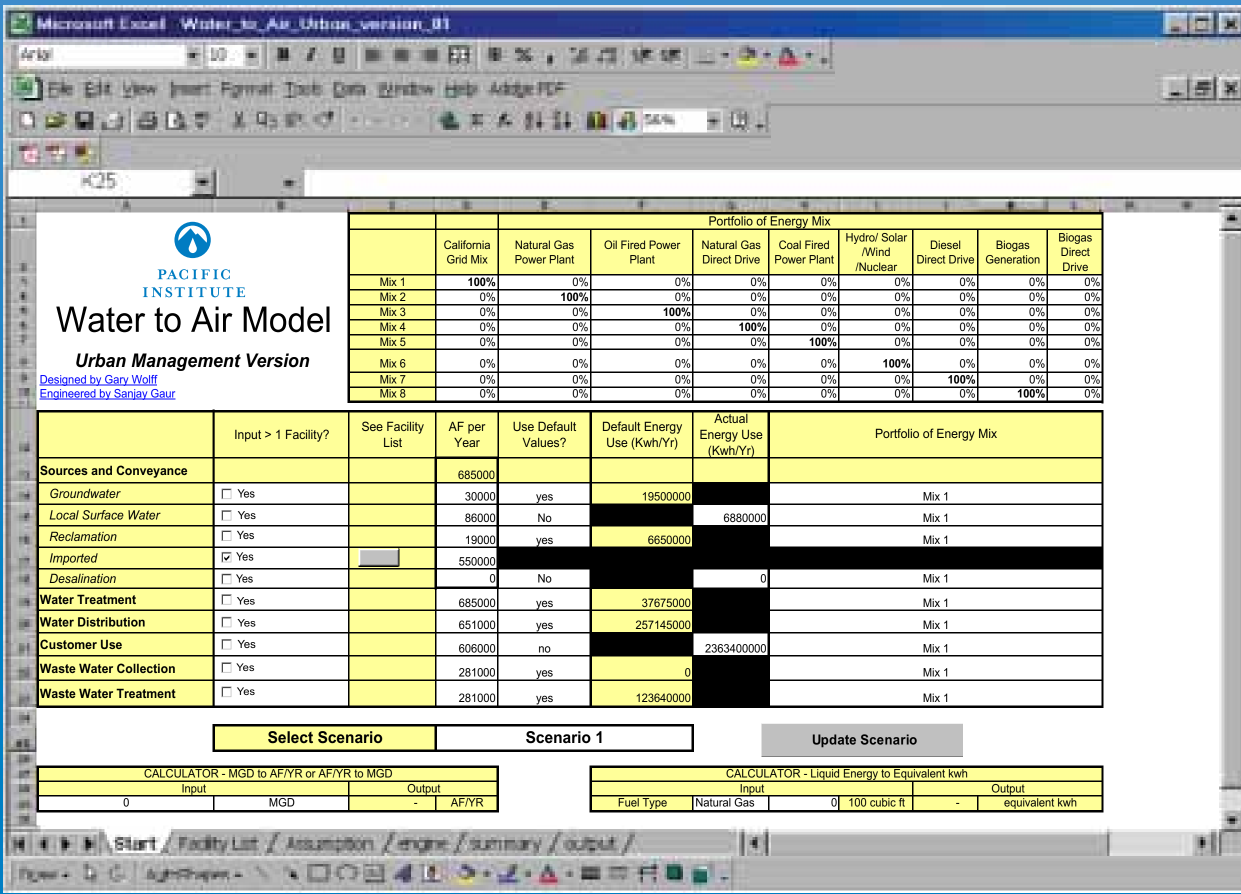
Both models also require users to specify a mix of energy for every facility. A mix can be, for example, 100% electricity from the California Grid. Or it could be 50% from the Grid and 50% from hydroelectric plants. Up to nine sources of energy can be combined to make a mix, and the model allows users to specify as many as eight mixes. If users know their electricity comes from a particular utility, they can contact the utility and find out the percentages to use (e.g., of natural gas, coal, and nuclear) to create a local grid mix. Energy sources in the model also include some non-electric options like direct drive diesel pumps, which are widely used in agriculture.

The mix to use if you know nothing about your energy sources is 100% California Grid. This is average electricity purchased from the average electric utility in California.

Air pollution emissions factors are embedded in the models for each of the nine types of energy sources. Appendix B describes the data sources for the emissions factors. The models do not allow emissions factors to be changed at present. Again, users beware: model outputs may not be accurate for your particular circumstances. Nonetheless, the models provide at least a sense of the relative magnitude of potential energy and air quality impacts.

The model estimates average annual energy use and emissions for two scenarios created by the user, and also calculates the differences in energy use and emissions between the two scenarios. By running the model a number of times, users can evaluate and compare as many scenarios as they please.

**Diagram 1** Start Tab for a San Diego Scenario One



Microsoft Excel - Water_to_Air_Urban_version_01

PACIFIC INSTITUTE

Water to Air Model

*Urban Management Version*

Designed by Gary Wolff

Engineered by Sanjay Gaur

| | Portfolio of Energy Mix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | California Grid Mix | Natural Gas Power Plant | Oil Fired Power Plant | Natural Gas Direct Drive | Coal Fired Power Plant | Hydro/ Solar /Wind /Nuclear | Diesel Direct Drive | Biogas Generation | Biogas Direct Drive |
| Mix 1 | **100%** | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 2 | 0% | **100%** | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 3 | 0% | 0% | **100%** | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 4 | 0% | 0% | 0% | **100%** | 0% | 0% | 0% | 0% | 0% |
| Mix 5 | 0% | 0% | 0% | 0% | **100%** | 0% | 0% | 0% | 0% |
| Mix 6 | 0% | 0% | 0% | 0% | 0% | **100%** | 0% | 0% | 0% |
| Mix 7 | 0% | 0% | 0% | 0% | 0% | 0% | **100%** | 0% | 0% |
| Mix 8 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | **100%** | 0% |

| | Input > 1 Facility? | See Facility List | AF per Year | Use Default Values? | Default Energy Use (Kwh/Yr) | Actual Energy Use (Kwh/Yr) | Portfolio of Energy Mix |
|---|---|---|---|---|---|---|---|
| **Sources and Conveyance** | | | 685000 | | | | |
| *Groundwater* | ☐ Yes | | 30000 | yes | 19500000 | | Mix 1 |
| *Local Surface Water* | ☐ Yes | | 86000 | No | | 6880000 | Mix 1 |
| *Reclamation* | ☐ Yes | | 19000 | yes | 6650000 | | Mix 1 |
| *Imported* | ☑ Yes | | 550000 | | | | |
| *Desalination* | ☐ Yes | | 0 | No | | 0 | Mix 1 |
| **Water Treatment** | ☐ Yes | | 685000 | yes | 37675000 | | Mix 1 |
| **Water Distribution** | ☐ Yes | | 651000 | yes | 257145000 | | Mix 1 |
| **Customer Use** | ☐ Yes | | 606000 | no | | 2363400000 | Mix 1 |
| **Waste Water Collection** | ☐ Yes | | 281000 | yes | 0 | | Mix 1 |
| **Waste Water Treatment** | ☐ Yes | | 281000 | yes | 123640000 | | Mix 1 |

**Select Scenario** | **Scenario 1** | **Update Scenario**

| CALCULATOR - MGD to AF/YR or AF/YR to MGD | | | |
|---|---|---|---|
| Input | | Output | |
| 0 | MGD | - | AF/YR |

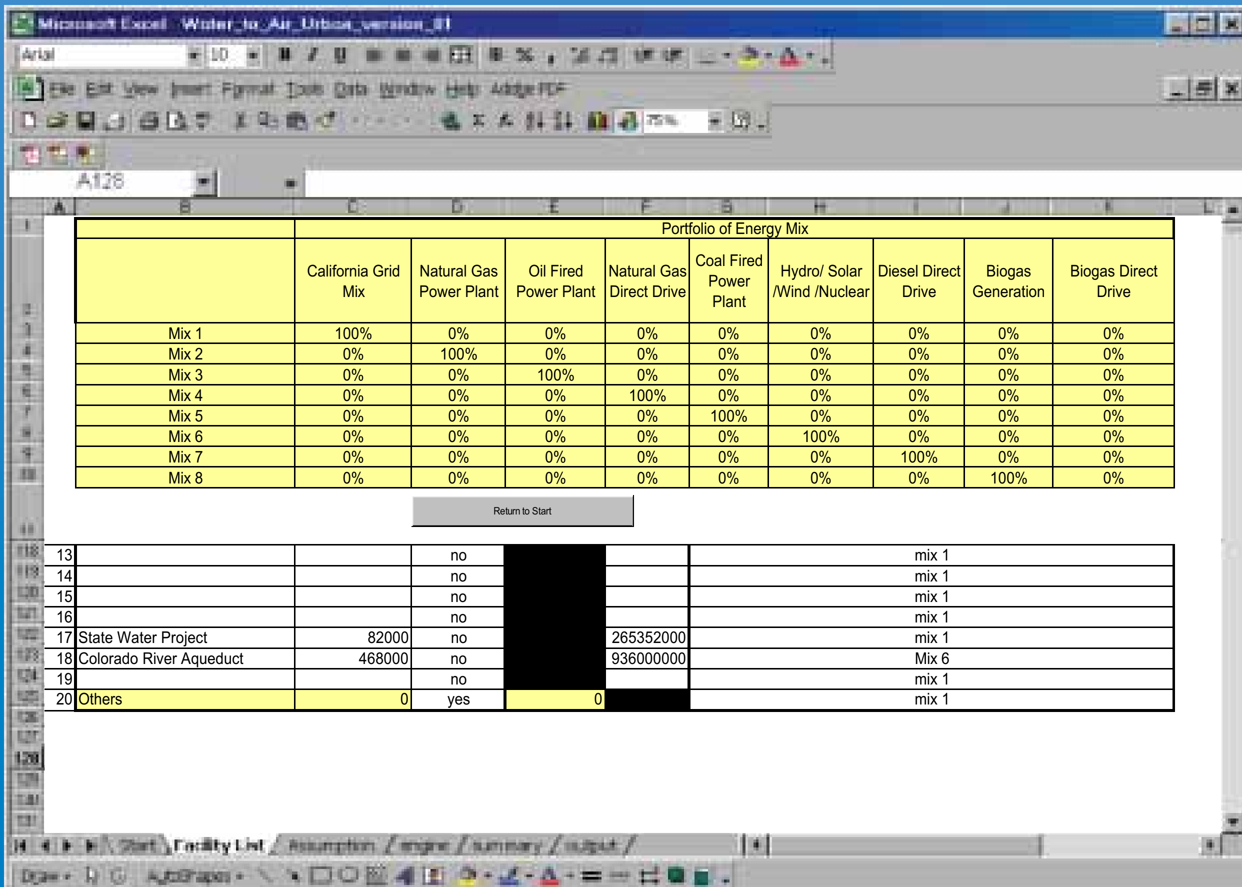
| CALCULATOR - Liquid Energy to Equivalent kwh | | | | | |
|---|---|---|---|---|---|
| Input | | | | Output | |
| Fuel Type | Natural Gas | 0 | 100 cubic ft | - | equivalent kwh |

Start / Facility List / Assumption / engine / summary / output /

## SAMPLE MODEL RUN: URBAN

Diagrams 1 and 2 show inputs for a possible Scenario One for San Diego County. The Scenario we've presented is an estimate for the service area of the San Diego County Water Authority (SDCWA) in 2003, assuming energy to run the Colorado River Aqueduct is 100% hydroelectric, and all other energy comes from the California Grid.

**Diagram 2** Imported Water Facility Spreadsheet for a San Diego Scenario One

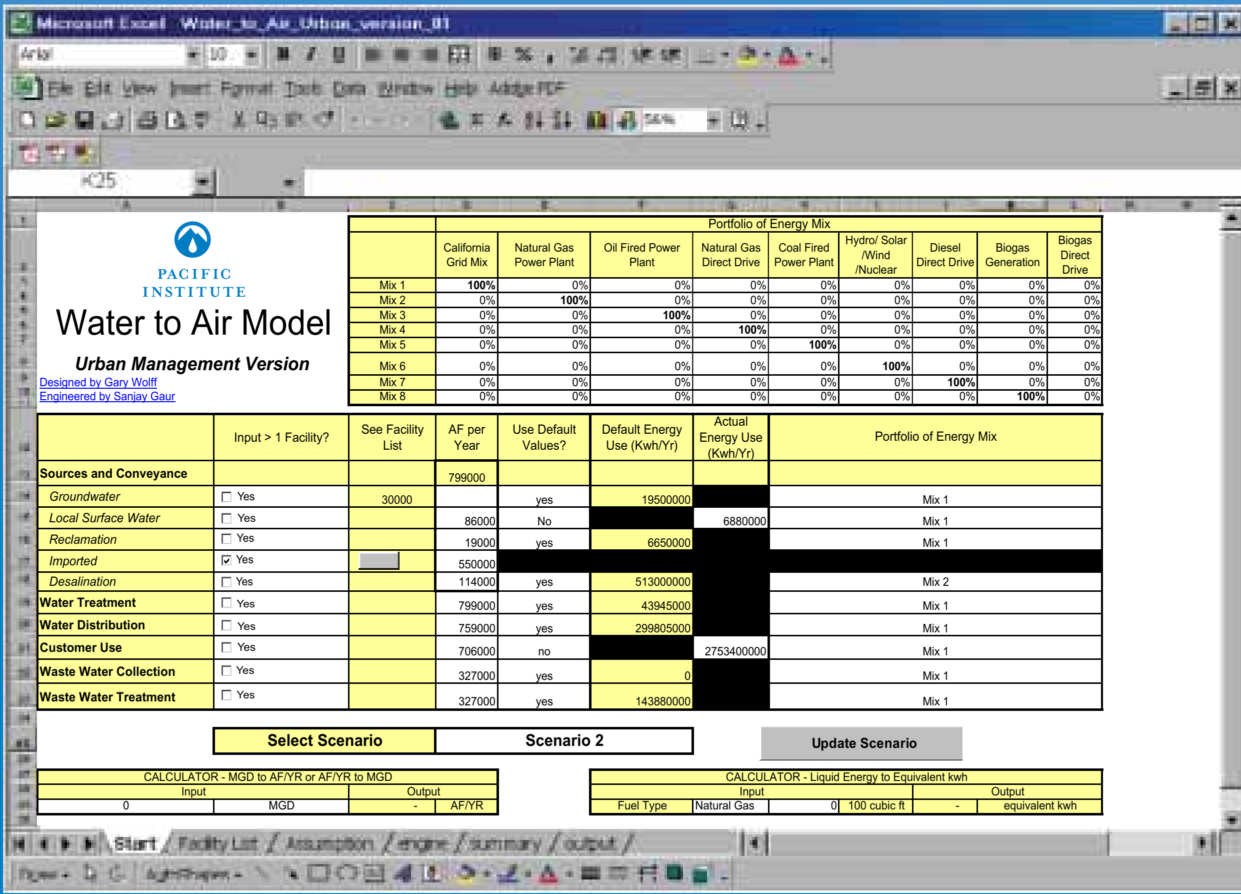


| | Portfolio of Energy Mix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | California Grid Mix | Natural Gas Power Plant | Oil Fired Power Plant | Natural Gas Direct Drive | Coal Fired Power Plant | Hydro/ Solar /Wind /Nuclear | Diesel Direct Drive | Biogas Generation | Biogas Direct Drive |
| Mix 1 | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 2 | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 3 | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 4 | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% |
| Mix 5 | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% |
| Mix 6 | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% |
| Mix 7 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% |
| Mix 8 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |

Return to Start

| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | | | no | | | mix 1 |
| 14 | | | no | | | mix 1 |
| 15 | | | no | | | mix 1 |
| 16 | | | no | | | mix 1 |
| 17 | State Water Project | 82000 | no | | 265352000 | mix 1 |
| 18 | Colorado River Aqueduct | 468000 | no | | 936000000 | Mix 6 |
| 19 | | | no | | | mix 1 |
| 20 | Others | 0 | yes | 0 | | mix 1 |

**Diagram 3** Start Tab for a San Diego Scenario Two




We then created a Scenario Two that differed from Scenario One in only two ways. First, it provides an additional 100,000 acre-feet of water per year *to consumers* from seawater desalination plants.[1] Second, we specified average natural gas as the source of energy for these seawater desalination plants, rather than the California Grid. This illustration DOES NOT represent a real choice being considered by the SDCWA. It is interesting, however, since seawater desalination is being explored in several Southern California jurisdictions, and because at least some of the possible facilities might be co-located with natural gas-generating facilities. Only one input screen differs between these scenarios (Diagram 3).

1 Note that an additional 100,000 af/yr delivered to customers requires 114,000 af/yr of water produced at the seawater desalination plant. This is because 7% water is believed to be lost in distribution in San Diego County (100,000/0.93 = 108,000), and another 5% is believed to be lost in the treatment plants (108,000/0.95 = 114,000). Also, the quantity of wastewater to be collected increases by only 46,000 af since 54% of water delivered to customers in San Diego County is believed to be used consumptively. These types of water losses will be implicit in the model inputs users choose. For example, inputting a total for treatment of 108,000 af/yr while inputting 100,000 af/yr for the total of water distributed implies a loss in distribution of 7%.

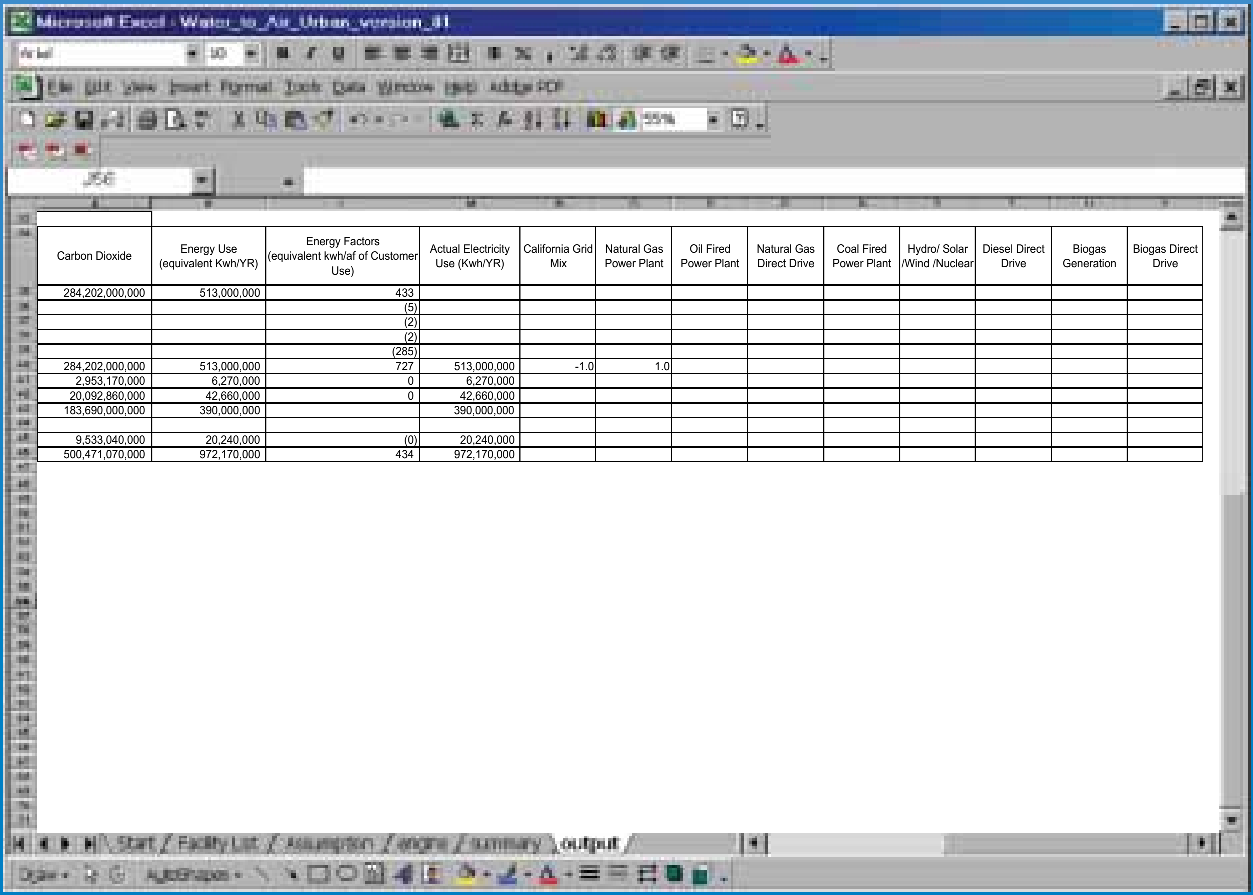
**Diagram 4A** Urban Model Output Tab, Lower Third, Left Half

| Difference Between Scenarios ( Non-Zero Values will only appear) | AF per Year | Total organic gases | Reactive organic gases | Carbon monoxide | Nitrogen oxides | Sulfur oxides | Total particulates | Particulates < 10 microns |
|---|---|---|---|---|---|---|---|---|
| | | Grams/ Year | | | | | | |
| **Sources & Conveyance** | 114,000 | 75,200,670 | 14,918,040 | 160,553,610 | 161,820,720 | 4,991,490 | 20,242,980 | 19,134,900 |
| *Groundwater* | | | | | | | | |
| *Surface Water* | | | | | | | | |
| *Reclamation* | | | | | | | | |
| *Imported* | | | | | | | | |
| *Desalination* | 114,000 | 75,200,670 | 14,918,040 | 160,553,610 | 161,820,720 | 4,991,490 | 20,242,980 | 19,134,900 |
| **Water Treatment** | 114,000 | 384,665 | 92,294 | 1,323,284 | 646,249 | 61,571 | 135,244 | 113,863 |
| **Water Distribution** | 108,000 | 2,617,191 | 627,955 | 9,003,393 | 4,396,966 | 418,921 | 920,176 | 774,706 |
| **Customer Use** | 100,000 | 23,926,500 | 5,740,800 | 82,309,500 | 40,197,300 | 3,829,800 | 8,412,300 | 7,082,400 |
| **Waste Water Collection** | 46,000 | | | | | | | |
| **Waste Water Treatment** | 46,000 | 1,241,724 | 297,933 | 4,271,652 | 2,086,137 | 198,757 | 436,577 | 367,558 |
| **Total** | | 103,370,750 | 21,677,022 | 257,461,439 | 209,147,372 | 9,500,539 | 30,147,277 | 27,473,427 |

This report was created on
10/20/04 10:53
Designed by Gary Wolff

Diagrams 4A and 4B show the estimated increase in energy use and emissions from moving to Scenario Two from Scenario One. Diagram 4A shows the left half of the lower third of the output tab; Diagram 4B shows the right half of the lower third of the output tab. Since units for emissions are grams per year, the increases in emissions shown in Diagram 4A are large numbers. To see the scale of these emissions increases, consider that the South Coast Air Quality Management District imposes fees on emissions of nitrogen oxides, sulfur oxides, and particulate matter in excess of four tons per year. The output in Diagram 4A shows emissions of these compounds far greater than four tons per year. Converting to pounds at 454 grams per pound, and to tons at 2000 pounds per ton, the model estimates that implementing Scenario Two would increase annual emissions of nitrogen oxides, sulfur oxides, and total particulates by about 230, 10, and 33 tons per year, respectively, in comparison with Scenario One.

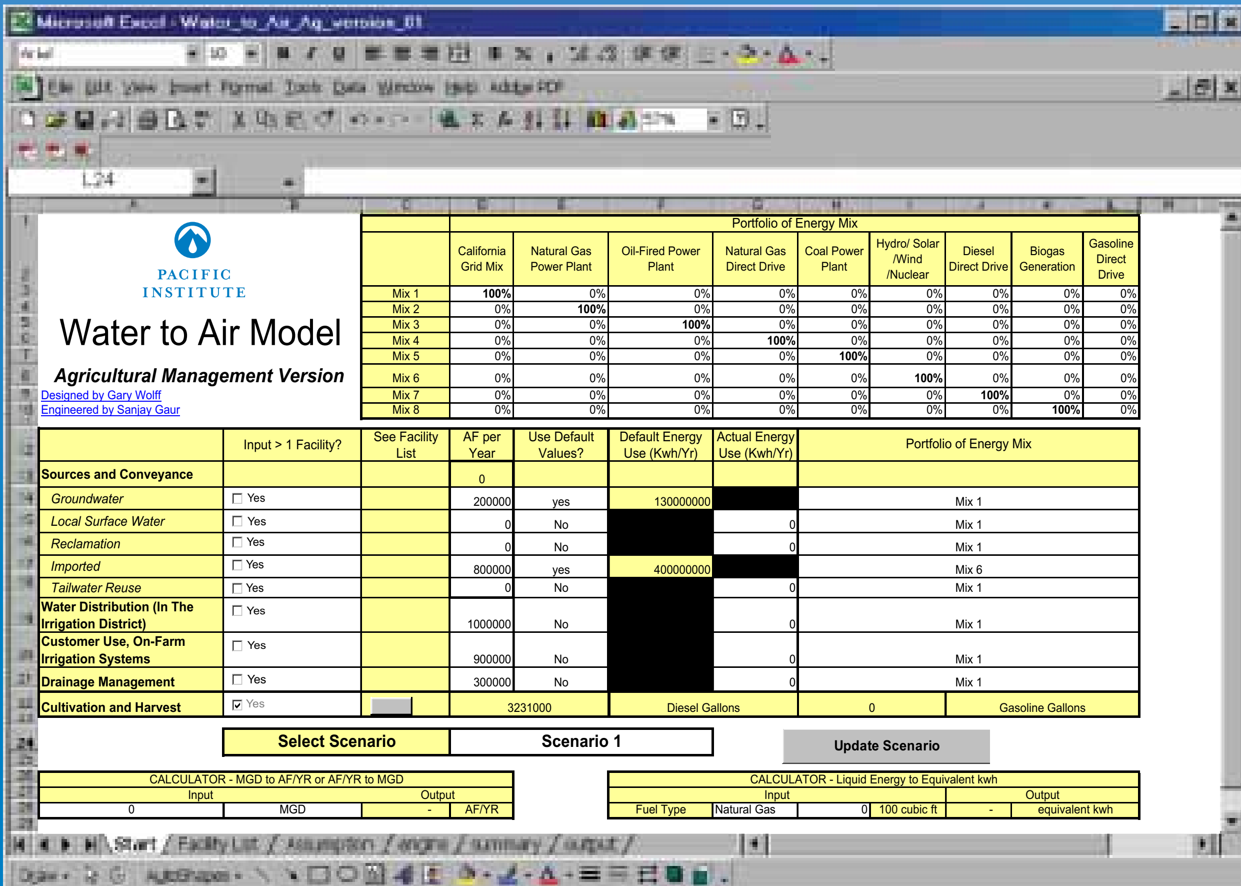
**Diagram 4B** Urban Model Output Tab, Lower Third, Right Half



| Carbon Dioxide | Energy Use (equivalent Kwh/YR) | Energy Factors (equivalent kwh/af of Customer Use) | Actual Electricity Use (Kwh/YR) | California Grid Mix | Natural Gas Power Plant | Oil Fired Power Plant | Natural Gas Direct Drive | Coal Fired Power Plant | Hydro/ Solar /Wind /Nuclear | Diesel Direct Drive | Biogas Generation | Biogas Direct Drive |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 284,202,000,000 | 513,000,000 | 433 | | | | | | | | | | |
| | | (5) | | | | | | | | | | |
| | | (2) | | | | | | | | | | |
| | | (2) | | | | | | | | | | |
| | | (285) | | | | | | | | | | |
| 284,202,000,000 | 513,000,000 | 727 | 513,000,000 | -1.0 | 1.0 | | | | | | | |
| 2,953,170,000 | 6,270,000 | 0 | 6,270,000 | | | | | | | | | |
| 20,092,860,000 | 42,660,000 | 0 | 42,660,000 | | | | | | | | | |
| 183,690,000,000 | 390,000,000 | | 390,000,000 | | | | | | | | | |
| | | | | | | | | | | | | |
| 9,533,040,000 | 20,240,000 | (0) | 20,240,000 | | | | | | | | | |
| 500,471,070,000 | 972,170,000 | 434 | 972,170,000 | | | | | | | | | |

Similarly, Diagram 4B shows a large increase in kwh per year, a little over 972 million. Note that the increase in energy use (equivalent kwh per year) and actual electricity use (kwh per year) shown in Diagram 4B are the same in this example. They would not be if one or more energy mixes included direct drive pumps powered, for example, by natural gas, diesel, or biogas. We included these totals separately in the model output so that impacts on the electric grid can be evaluated separately from total energy impacts.

**Diagram 5** Start Tab for a Westlands Water District Scenario One




| | Portfolio of Energy Mix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | California Grid Mix | Natural Gas Power Plant | Oil-Fired Power Plant | Natural Gas Direct Drive | Coal Power Plant | Hydro/ Solar /Wind /Nuclear | Diesel Direct Drive | Biogas Generation | Gasoline Direct Drive |
| Mix 1 | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 2 | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 3 | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 4 | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% |
| Mix 5 | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% |
| Mix 6 | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% |
| Mix 7 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% |
| Mix 8 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |

| | Input > 1 Facility? | See Facility List | AF per Year | Use Default Values? | Default Energy Use (Kwh/Yr) | Actual Energy Use (Kwh/Yr) | Portfolio of Energy Mix | |
|---|---|---|---|---|---|---|---|---|
| **Sources and Conveyance** | | | 0 | | | | | |
| *Groundwater* | ☐ Yes | | 200000 | yes | 130000000 | | Mix 1 | |
| *Local Surface Water* | ☐ Yes | | 0 | No | | 0 | Mix 1 | |
| *Reclamation* | ☐ Yes | | 0 | No | | 0 | Mix 1 | |
| *Imported* | ☐ Yes | | 800000 | yes | 400000000 | | Mix 6 | |
| *Tailwater Reuse* | ☐ Yes | | 0 | No | | 0 | Mix 1 | |
| **Water Distribution (In The Irrigation District)** | ☐ Yes | | 1000000 | No | | 0 | Mix 1 | |
| **Customer Use, On-Farm Irrigation Systems** | ☐ Yes | | 900000 | No | | 0 | Mix 1 | |
| **Drainage Management** | ☐ Yes | | 300000 | No | | 0 | Mix 1 | |
| **Cultivation and Harvest** | ☑ Yes | | 3231000 | | Diesel Gallons | | 0 | Gasoline Gallons |

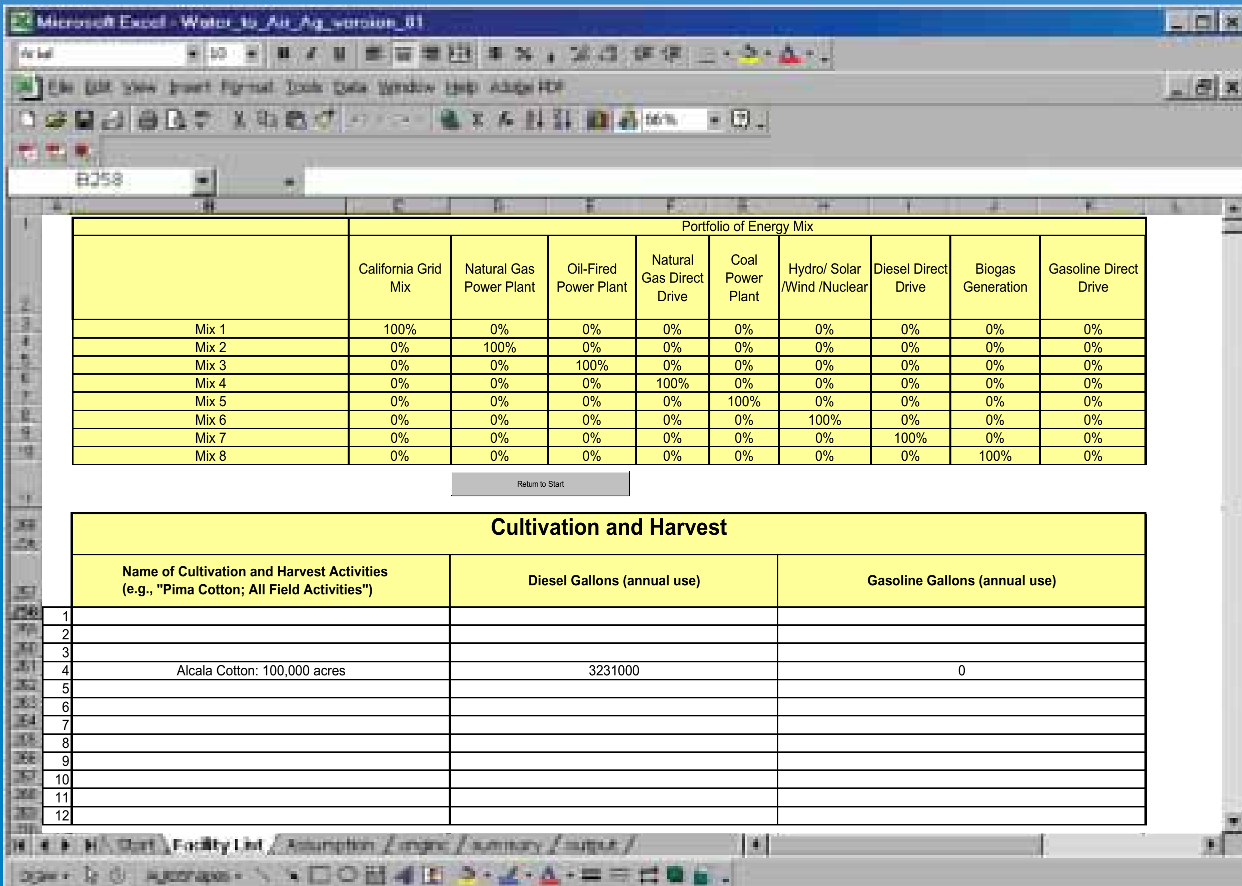
| CALCULATOR - MGD to AF/YR or AF/YR to MGD | | | |
|---|---|---|---|
| Input | | Output | |
| 0 | MGD | - | AF/YR |

| CALCULATOR - Liquid Energy to Equivalent kwh | | | | | |
|---|---|---|---|---|---|
| Input | | | | Output | |
| Fuel Type | Natural Gas | 0 | 100 cubic ft | - | equivalent kwh |

## SAMPLE MODEL RUN: AGRICULTURAL

Diagrams 5 and 6 show inputs for a possible Scenario One for growing cotton on 100,000 acres in the Westlands Water District in Central California. The Scenario we've presented assumes energy to deliver water to Westlands via the Central Valley Project is 100% hydroelectric, groundwater pumps on farms use electricity from the California Grid, and fuel for cultivation and harvest of Alcala Cotton is diesel fuel (see Table A-3 for the source of this data). We've also arbitrarily assumed that 10% of source water is lost during distribution within the irrigation district (e.g., percolation from distribution canals), and that 2/3 of

**Diagram 6** Cultivation and Harvest Facility Spreadsheet for a Westlands Water District Scenario One



| | Portfolio of Energy Mix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | California Grid Mix | Natural Gas Power Plant | Oil-Fired Power Plant | Natural Gas Direct Drive | Coal Power Plant | Hydro/ Solar /Wind /Nuclear | Diesel Direct Drive | Biogas Generation | Gasoline Direct Drive |
| Mix 1 | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 2 | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 3 | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 4 | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% |
| Mix 5 | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% |
| Mix 6 | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% |
| Mix 7 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% |
| Mix 8 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |

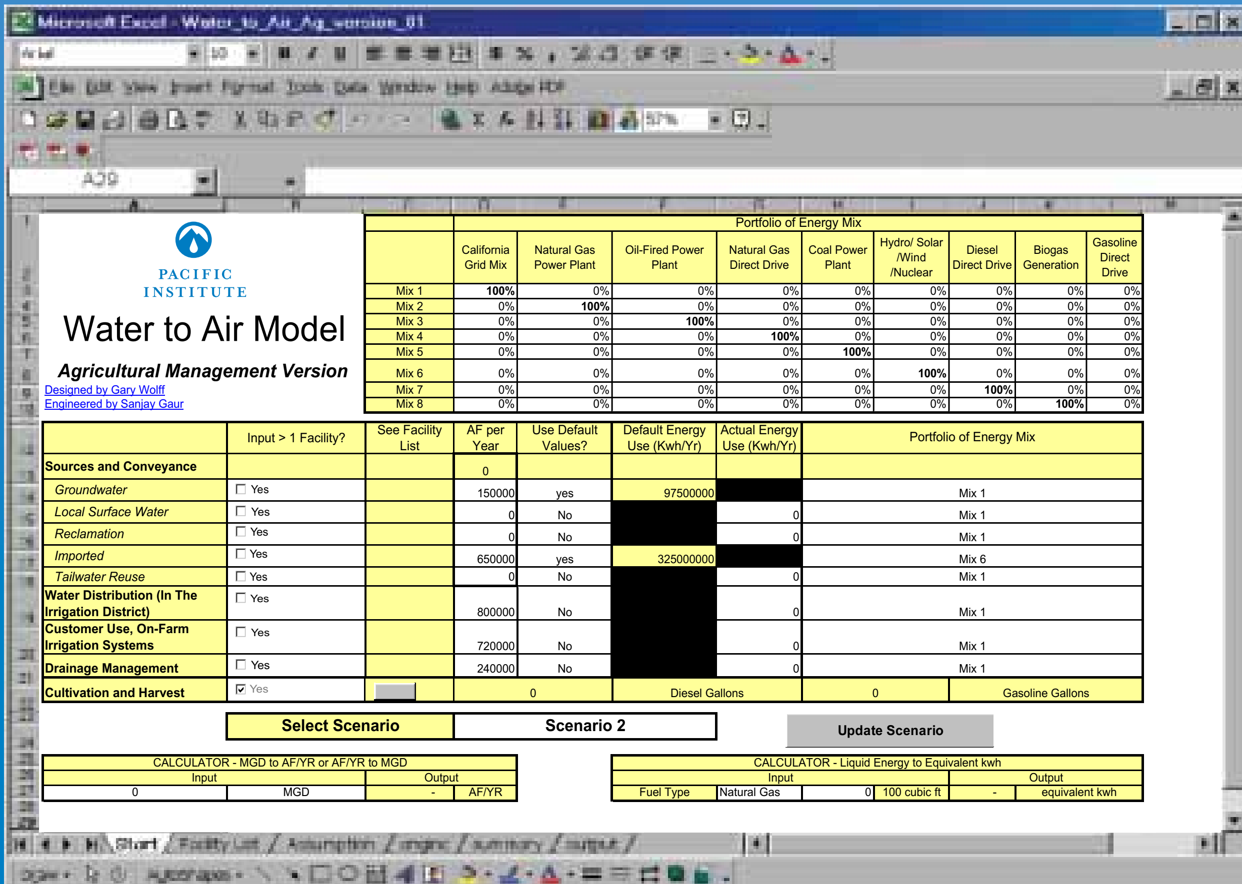
Return to Start

**Cultivation and Harvest**

| | Name of Cultivation and Harvest Activities (e.g., "Pima Cotton; All Field Activities") | Diesel Gallons (annual use) | Gasoline Gallons (annual use) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | Alcala Cotton: 100,000 acres | 3231000 | 0 |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |

water applied on the fields is used consumptively. These assumptions illustrate water loss issues that users of the model should think about if they need to input a quantity of water on the start tab that they have not actually measured somewhere.

**Diagram 7** Start Tab for a Westlands Water District Scenario Two




| | Portfolio of Energy Mix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | California Grid Mix | Natural Gas Power Plant | Oil-Fired Power Plant | Natural Gas Direct Drive | Coal Power Plant | Hydro/ Solar /Wind /Nuclear | Diesel Direct Drive | Biogas Generation | Gasoline Direct Drive |
| Mix 1 | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 2 | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 3 | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 4 | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% |
| Mix 5 | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% |
| Mix 6 | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% |
| Mix 7 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% |
| Mix 8 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |

| | Input > 1 Facility? | See Facility List | AF per Year | Use Default Values? | Default Energy Use (Kwh/Yr) | Actual Energy Use (Kwh/Yr) | Portfolio of Energy Mix |
|---|---|---|---|---|---|---|---|
| **Sources and Conveyance** | | | 0 | | | | |
| *Groundwater* | ☐ Yes | | 150000 | yes | 97500000 | | Mix 1 |
| *Local Surface Water* | ☐ Yes | | 0 | No | | 0 | Mix 1 |
| *Reclamation* | ☐ Yes | | 0 | No | | 0 | Mix 1 |
| *Imported* | ☐ Yes | | 650000 | yes | 325000000 | | Mix 6 |
| *Tailwater Reuse* | ☐ Yes | | 0 | No | | 0 | Mix 1 |
| **Water Distribution (In The Irrigation District)** | ☐ Yes | | 800000 | No | | 0 | Mix 1 |
| **Customer Use, On-Farm Irrigation Systems** | ☐ Yes | | 720000 | No | | 0 | Mix 1 |
| **Drainage Management** | ☐ Yes | | 240000 | No | | 0 | Mix 1 |
| **Cultivation and Harvest** | ☑ Yes | | 0 | | Diesel Gallons | 0 | Gasoline Gallons |

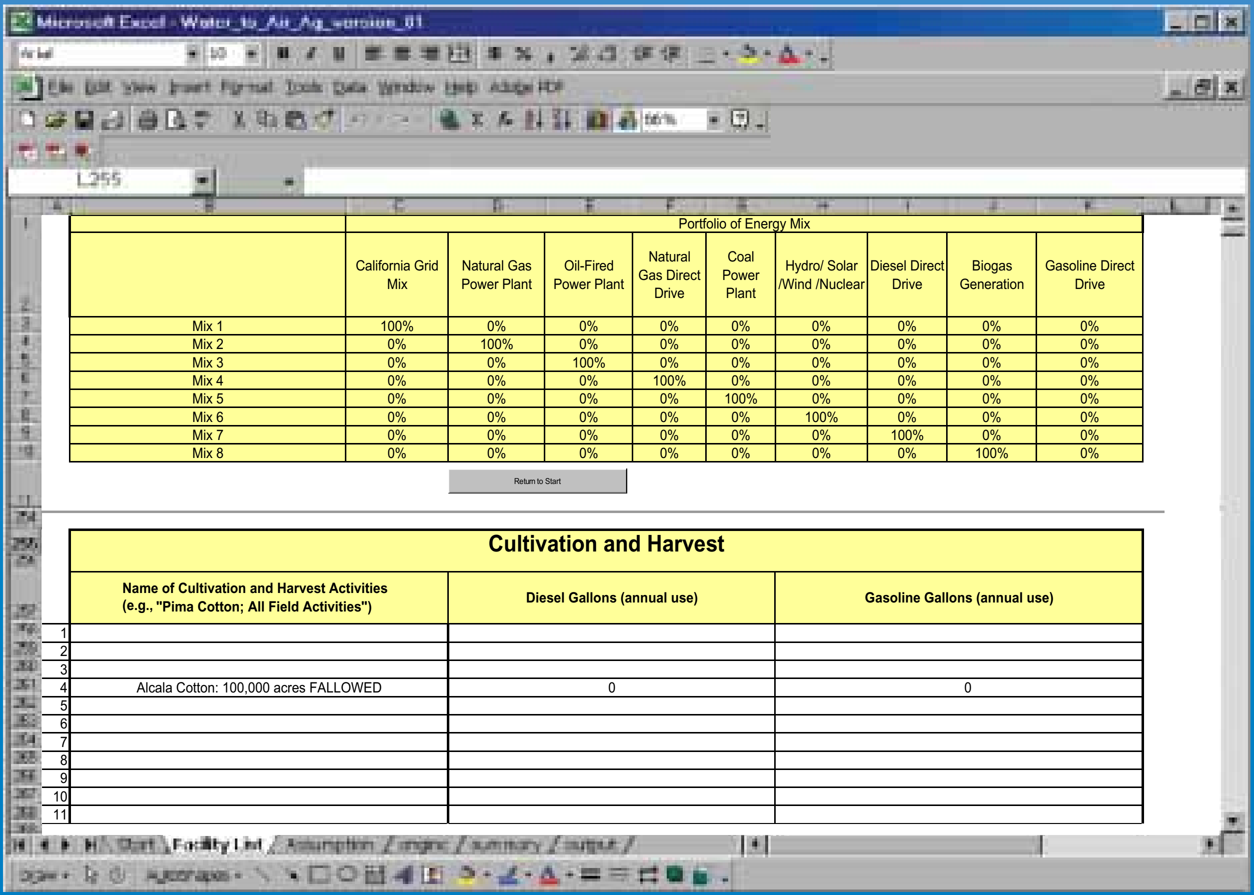
**Select Scenario** | **Scenario 2** | **Update Scenario**

| CALCULATOR - MGD to AF/YR or AF/YR to MGD | | | |
|---|---|---|---|
| Input | | Output | |
| 0 | MGD | - | AF/YR |

| CALCULATOR - Liquid Energy to Equivalent kwh | | | | | |
|---|---|---|---|---|---|
| Input | | | | Output | |
| Fuel Type | Natural Gas | 0 | 100 cubic ft | - | equivalent kwh |

We then created a Scenario Two that represents one possible way of permanently fallowing 100,000 acres of cotton-growing land in Westlands. Our Scenario Two assumes that the land reverts to natural habitat and that 75% of the water formerly applied to it is left in the Delta for environmental uses, and 25% of the water formerly applied to it is no longer pumped from the ground. We arbitrarily assume 200,000 acre-feet per year of source water is saved by fallowing 100,000 acres of cotton, which is equal to 180,000 acre-feet per year applied in the field under the arbitrary assumption in Scenario One that 10%

**Diagram 8** Cultivation and Harvest Facility Spreadsheet for a Westlands Water District Scenario Two



| | Portfolio of Energy Mix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | California Grid Mix | Natural Gas Power Plant | Oil-Fired Power Plant | Natural Gas Direct Drive | Coal Power Plant | Hydro/ Solar /Wind /Nuclear | Diesel Direct Drive | Biogas Generation | Gasoline Direct Drive |
| Mix 1 | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 2 | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 3 | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 4 | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% |
| Mix 5 | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% |
| Mix 6 | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% |
| Mix 7 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% |
| Mix 8 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |

Return to Start

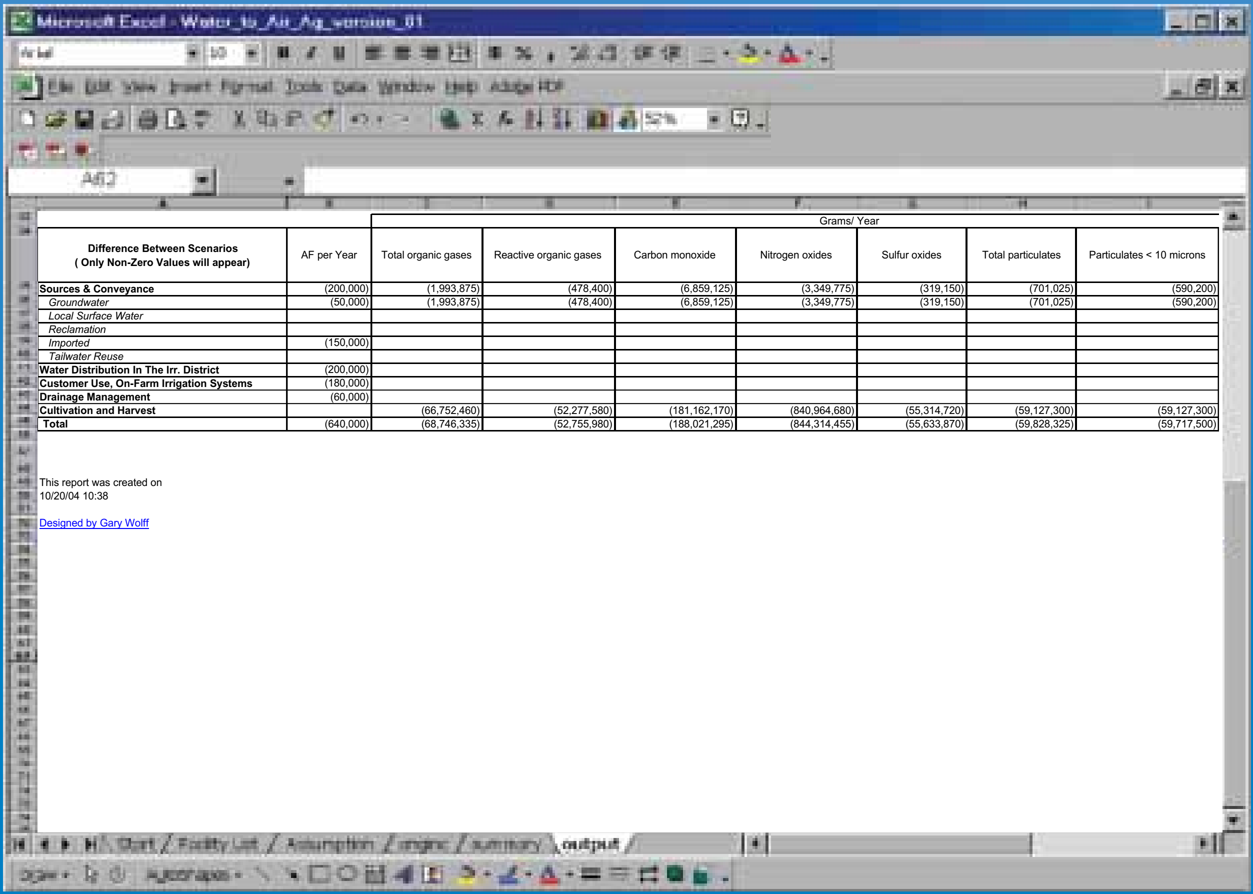
**Cultivation and Harvest**

| | Name of Cultivation and Harvest Activities (e.g., "Pima Cotton; All Field Activities") | Diesel Gallons (annual use) | Gasoline Gallons (annual use) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | Alcala Cotton: 100,000 acres FALLOWED | 0 | 0 |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |

of source water is lost during distribution within the irrigation district. This illustration is overly simplified in a number of ways and DOES NOT represent a real choice faced by Westlands. It is interesting, however, since Westlands is actively discussing the possibility of permanently fallowing 100,000 acres.

Diagrams 7 and 8 show the revised start tab and the revised cultivation and harvest facility spreadsheet used in Scenario Two. These are the only differences in the model between Scenarios One and Two.

**Diagram 9A** Agricultural Model Output Tab, Lower Third, Left Half




| Difference Between Scenarios ( Only Non-Zero Values will appear) | AF per Year | Grams/ Year | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Total organic gases | Reactive organic gases | Carbon monoxide | Nitrogen oxides | Sulfur oxides | Total particulates | Particulates < 10 microns |
| **Sources & Conveyance** | (200,000) | (1,993,875) | (478,400) | (6,859,125) | (3,349,775) | (319,150) | (701,025) | (590,200) |
| *Groundwater* | (50,000) | (1,993,875) | (478,400) | (6,859,125) | (3,349,775) | (319,150) | (701,025) | (590,200) |
| *Local Surface Water* | | | | | | | | |
| *Reclamation* | | | | | | | | |
| *Imported* | (150,000) | | | | | | | |
| *Tailwater Reuse* | | | | | | | | |
| **Water Distribution In The Irr. District** | (200,000) | | | | | | | |
| **Customer Use, On-Farm Irrigation Systems** | (180,000) | | | | | | | |
| **Drainage Management** | (60,000) | | | | | | | |
| **Cultivation and Harvest** | | (66,752,460) | (52,277,580) | (181,162,170) | (840,964,680) | (55,314,720) | (59,127,300) | (59,127,300) |
| **Total** | (640,000) | (68,746,335) | (52,755,980) | (188,021,295) | (844,314,455) | (55,633,870) | (59,828,325) | (59,717,500) |

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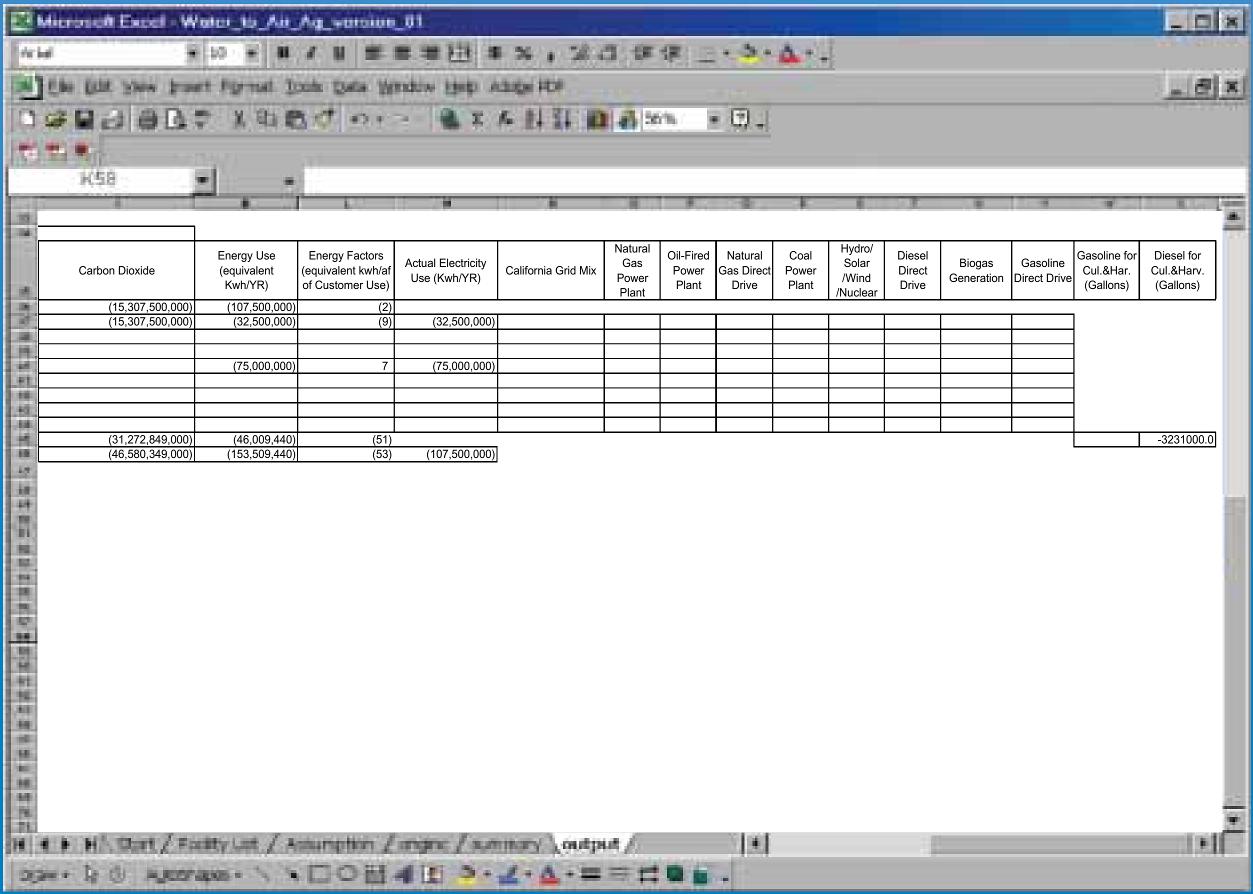
Diagrams 9A and 9B show the estimated decrease in energy use and emissions from moving to Scenario Two from Scenario One. The breakdown of emissions by type of water management activity (rows) in Diagram 9A shows that a reduction in imported water does not reduce emissions at all since it was assumed that imported water was pumped using hydroelectricity. Emissions reductions, under the assumptions made, result from less groundwater pumping (reduced use of electricity from the California Grid) and less cultivation and harvest (reduced use of diesel fuel to power tractors, etc.).

**Diagram 9B** Agricultural Model Output Tab, Lower Third, Right Half




| Carbon Dioxide | Energy Use (equivalent Kwh/YR) | Energy Factors (equivalent kwh/af of Customer Use) | Actual Electricity Use (Kwh/YR) | California Grid Mix | Natural Gas Power Plant | Oil-Fired Power Plant | Natural Gas Direct Drive | Coal Power Plant | Hydro/ Solar /Wind /Nuclear | Diesel Direct Drive | Biogas Generation | Gasoline Direct Drive | Gasoline for Cul.&Har. (Gallons) | Diesel for Cul.&Harv. (Gallons) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (15,307,500,000) | (107,500,000) | (2) | | | | | | | | | | | | |
| (15,307,500,000) | (32,500,000) | (9) | (32,500,000) | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | (75,000,000) | 7 | (75,000,000) | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| (31,272,849,000) | (46,009,440) | (51) | | | | | | | | | | | | -3231000.0 |
| (46,580,349,000) | (153,509,440) | (53) | (107,500,000) | | | | | | | | | | | |

Diagram 9B shows that fallowing 100,000 acres could save more than 150 million equivalent kwh per year, under the assumptions made. Of this amount, 107.5 million kwh per year would be electricity actually supplied by the grid. The remainder of the equivalent kilowatt-hours represents the energy in diesel fuel used directly, rather than indirectly via a power plant.

## HOW TO USE THE MODELS

This section describes how to use the Water to Air (WtoA) models available from **www.pacinst.org/resources/water_to_air_models** in more detail than the general discussion above. The model files are read-only, so you must "save as" to save scenarios and comparisons of scenarios that you create. This manual applies to the models labeled "Version 1." If other versions are created in the future, updates to the user manual will be available with them at **www.pacinst.org/publications**. Please direct any questions about the models to Gary Wolff, P.E., Ph.D., at the Pacific Institute (gwolff@pacinst.org or 510-251-1600 x102).

### Changing Security Settings

Depending on the version of Excel the user is operating, the security setting may need to be adjusted to enable Visual Basic code. If the user is operating Excel 2000 or an earlier version, then no security adjustment is required. If the user is operating Excel 2002, then a security adjustment must be made prior to running the WtoA Models. To determine which version of Excel you are using, please go to the "Help" prompt and select "About Microsoft Excel." The top section of the dialog box will inform the user which version of Excel is being used.

For Excel 2002 users, select the "Tools" prompt, then "Macro," then "Security." A dialog box will be displayed. Change the security setting to "Medium."

### Overview of the Models

Before we explain how to use the model, some basic overview information is provided. Each WtoA model has six sheets: start, facilities, assumption, engine, summary, and output. The user will only put information in the "Start" tab and possibly in the "Facility" tab if information is available for more than one facility. The only exception to this is in the Agricultural Management Version for the "facility" cultivation and harvest sheet. The user will have to provide information on cultivation and harvest in the "Facility" tab.

All information will only be inputted into white cells with a black border. The user will either input a value or select an option from a dropdown box. All yellow cells display information that cannot be changed. The "Start" tab is where the user can provide information on facilities and run the model. How to run the model will be explained in the next section. The "Assumption" tab provides information on estimates of energy usage by facilities, and air emission levels by energy sources. Also, basic conversion information is stored here. The next tab, "Engine," calculates emission levels for each facility. In addition, this sheet checks for potential errors. The "Summary" tab summarizes the information depending on the user's selection. The last sheet, "Output," displays two scenarios and the difference between them.

## Overview of Running the Models

To run either WtoA model, the user must create at least one scenario. A scenario is a description of a water system from sources through disposal (sources, treatment, distribution, customer uses, wastewater treatment). Each scenario is composed of facilities that use energy, the amount of water that flows into each facility, the amount of energy used at each facility, and the sources of energy for each facility. A facility is a place where water is pumped, treated, or used. Groundwater wells, treatment plants, and clothes washers are all facilities. One can input up to 19 named facilities within each category of facilities, such as water treatment plants. A 20th facility ("Other") is automatically calculated to have flow equal to the total flow for a category of facilities on the "Start" spreadsheet (e.g., water treatment plants), less the specifically named facilities that are input in the corresponding section (in this case, the water treatment plant section) of the facility spreadsheet.

Once the other three types of information (flow, energy use, and energy source) are provided for all facilities in a scenario (detailed instructions are presented below), the user simply selects the appropriate scenario (such as Scenario 1), then presses the "Update Scenario" button. This stores the appropriate information in the "Update" tab. The user is then able to compare this scenario with a second one. The user changes any values they wish, then selects the other scenario button (such as Scenario 2), and then presses "Update Scenario." After the completion of this task, the energy use, emission levels, and key inputs for BOTH SCENARIOS are displayed in the "Output" tab. The user can view the information, or simply print the tab. Note that this sheet displays three sections, Scenario 1, Scenario 2, and the differences between them. In the differences between scenarios, zero values have been suppressed for visual purposes. Thus if two scenarios are exactly the same, no information will be displayed in the difference between scenarios output.

## Detailed Explanation of How to Run the Models

When running WtoA model the first dialog box will ask the user whether to enable or disenable macros[2]. The user should select "enable macros." The second dialog box is a welcome message that asks the user to provide the name of their agency. The user should type in the agency they work for. This information will be automatically displayed in the summary output. Once this information is typed, select OK. The user then will see the "Start" tab or the first input sheet for WtoA. Diagram 10 shows the interface for the Urban Management Version.

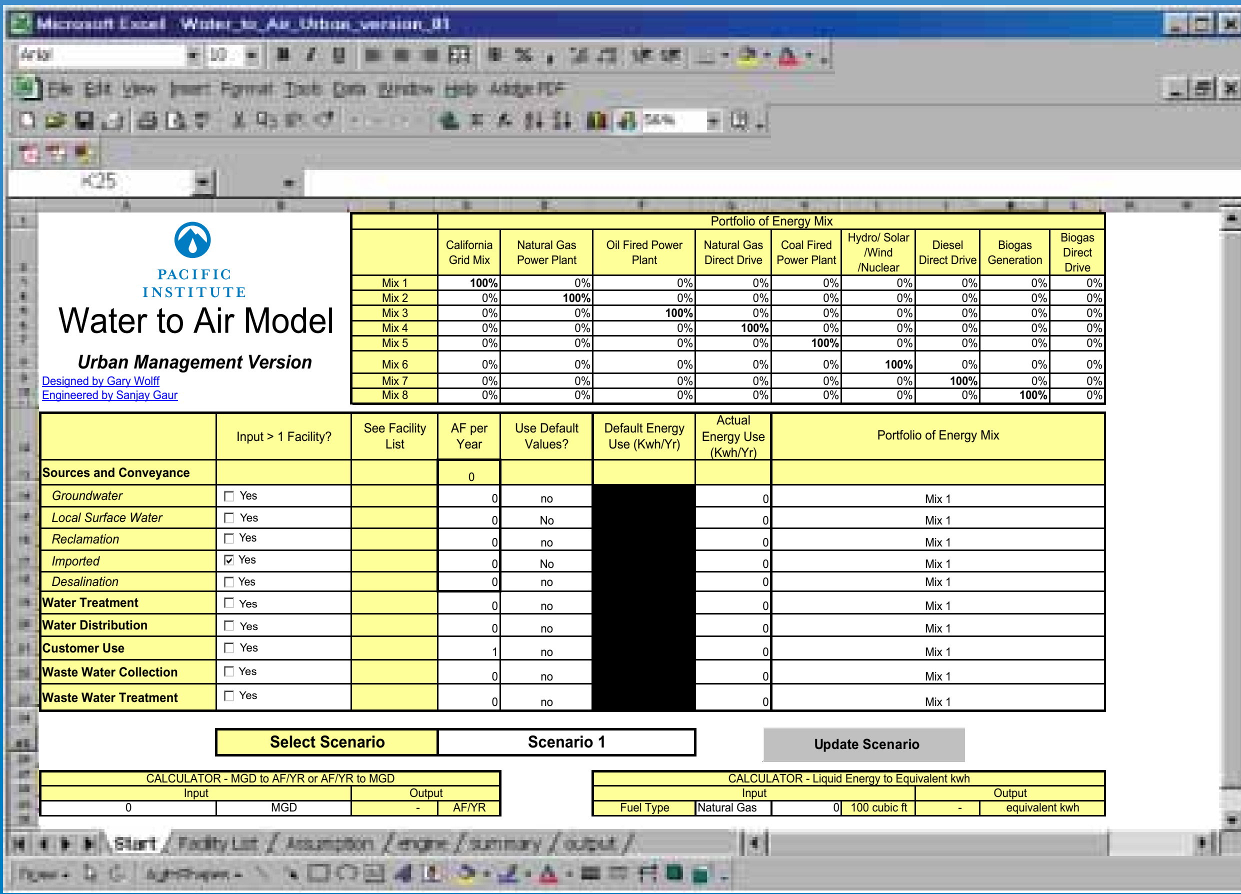
It is recommended that the user first select the appropriate energy mixes. As Diagram 10 shows, there are nine different types of energy sources. In addition, the user has the ability to create eight different energy mixes from these nine different sources. A user simply selects the percentage for each energy source that would create a mix that adds to 100%. In Diagram 10, Mix 1 is 100 percent California Grid mix. If a user creates a portfolio of energy sources that does not add to 100 percent, then the cells within that mix will turn red. In addition, the model will not run and an error message will be produced to inform the user to adjust the portfolio.

Once the appropriate energy mixes are selected, then the user should input information about the facilities. There are ten and nine categories of facilities on the "Start" spreadsheets of the Urban Management and Agricultural Management models, respectively.

To provide information on a facility the user simply inputs it. For instance, each facility requires acre-feet per year, a default energy value or actual energy use, and a source of energy (energy mix). If information for only one facility is available for the Urban Management version, it can be input on the "Start" tab. For the Agricultural Management version, however, the user is forced to provide information for cultivation and harvest on another spreadsheet. Once all required information is provided, the user can run a WtoA model. To run it, please see the section "Overview of Running the Model," above.

2 WtoA uses a series of macros or Visual Basic code to run the model.

**Diagram 10** Start Tab of the WtoA Urban Model

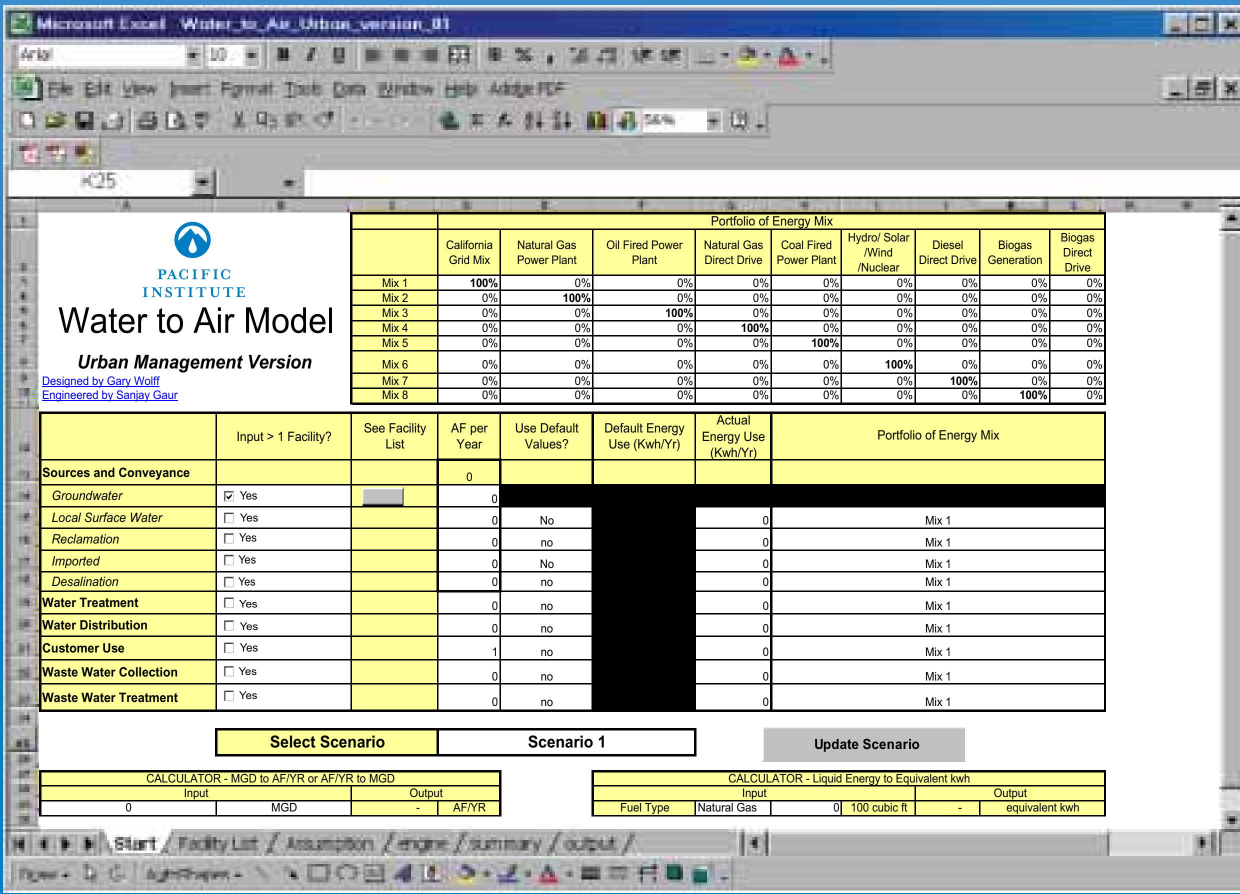



Because water quantity inputs must be in acre-feet per year (af/yr), we've provided a calculator to convert from millions of gallons per day (MGD) to af/yr (or the reverse). After converting MGD to af/yr, you must input the af/yr number manually.

Similarly, energy inputs must be in actual kilowatt-hours (kwh) per year or "equivalent" kilowatt-hours per year. An equivalent kwh is the amount of electricity that could be generated (on average) if a fuel (e.g., natural gas) were used in a power plant to generate electricity. This unit is necessary because sometimes energy other than electricity is used to directly pump or otherwise manage water. For example, natural gas and diesel fuel are used to directly drive pumps in some places. If you have this type of energy use, you must input equivalent kwh rather than hundreds of cubic feet (ccf) or gallons (g) of natural gas or diesel fuel, respectively. Again, we've provided a calculator to make these conversions. After converting from gas or liquid fuels to equivalent kwh, you must input the equivalent kwh in the appropriate row manually.

Conversion errors are common in performing the types of calculations in these models. Please use the calculators provided rather than a hand calculator to prevent such errors.

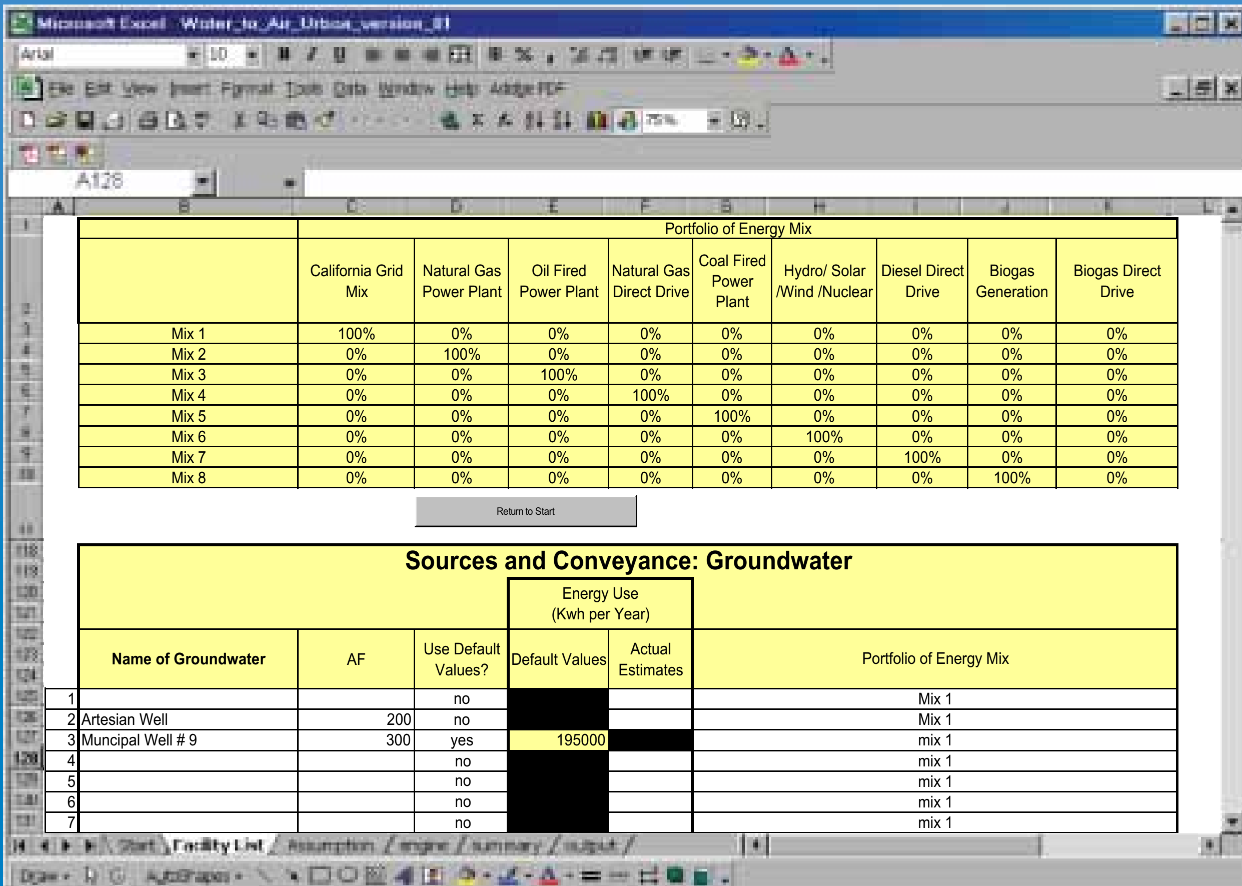
**Diagram 11** Listing More Than One Groundwater Facility




If more than one facility exists in a category, the user should select yes to input all facilities on the facility spreadsheet. For instance, if the user selects yes to "Input >1 Facility?," this will automatically display a button and disable the following cells for Groundwater in the "Start" tab: Use Default Value, Actual Energy Use, and Portfolio of Energy Mix. See Diagram 11 for a visual display.

The user then selects the button associated with Groundwater, which will automatically move the user to the Groundwater facility section. Diagram 12 shows what the user will see if one selects the "See Facility List" button for Groundwater.

The user can input 19 different Groundwater Facilities. Each facility require information on acre-feet per year (af/yr), whether to use Default Values or Actual Estimates of energy use, and Energy Mix. Also note that the top section of the window displays the energy mixes the user created in the "Start" tab. Once the information is provided the user simply hits "Return to Start" button, which will automatically guide the user back to the "Start" tab.



| | Portfolio of Energy Mix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | California Grid Mix | Natural Gas Power Plant | Oil Fired Power Plant | Natural Gas Direct Drive | Coal Fired Power Plant | Hydro/ Solar /Wind /Nuclear | Diesel Direct Drive | Biogas Generation | Biogas Direct Drive |
| Mix 1 | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 2 | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 3 | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% |
| Mix 4 | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% |
| Mix 5 | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% |
| Mix 6 | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% |
| Mix 7 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% | 0% |
| Mix 8 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |

Return to Start

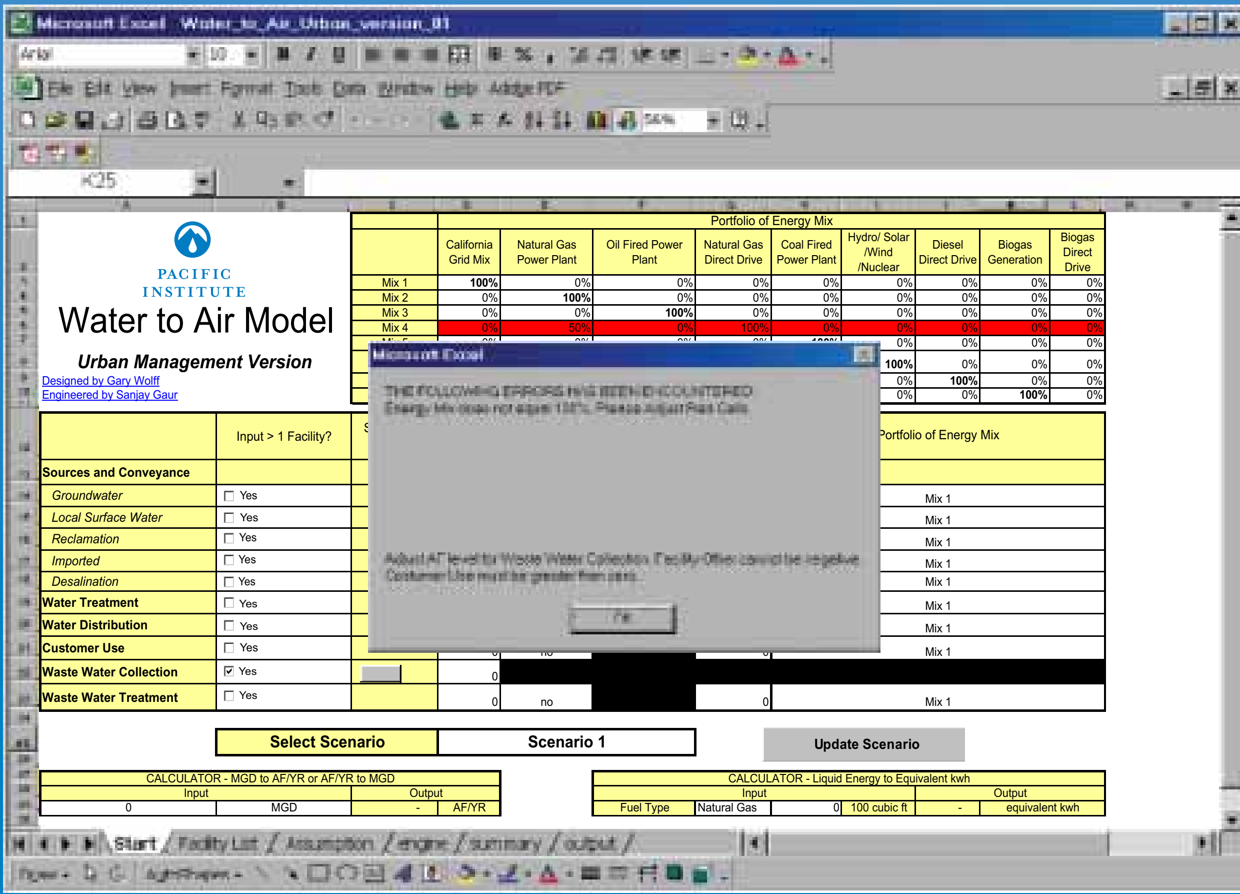
**Sources and Conveyance: Groundwater**

| | Name of Groundwater | AF | Use Default Values? | Energy Use (Kwh per Year): Default Values | Energy Use (Kwh per Year): Actual Estimates | Portfolio of Energy Mix |
|---|---|---|---|---|---|---|
| 1 | | | no | | | Mix 1 |
| 2 | Artesian Well | 200 | no | | | Mix 1 |
| 3 | Muncipal Well # 9 | 300 | yes | 195000 | | mix 1 |
| 4 | | | no | | | mix 1 |
| 5 | | | no | | | mix 1 |
| 6 | | | no | | | mix 1 |
| 7 | | | no | | | mix 1 |

One technical issue needs to be addressed regarding the relationship between the "Start" spreadsheet and the "Facility" spreadsheets. On the "Start" tab the user inputs the total amount of acre-feet of water per year for all facilities in that category, regardless if one has or does not have facility information. If a user has information about more than one facility, then the total amount input on the "Start" tab will be used on the facility worksheet to calculate unaccounted water automatically as facility number 20, "Others." Theoretically, "Others" can only be zero or positive, since there is no negative acre-feet of water. The WtoA model will check to ensure that "Other" is not negative for each type of facility during the "Updates of Scenario."

The only exception to the above rule is for the Agricultural Management version for facility cultivation and harvest. For this type of facility, the user only puts information on the amount of diesel and gasoline that is required for cultivation and harvest in the facility section. That is, totals are not input on the "Start" tab. The facility sheet is an area where the user can list the amount of diesel and

**Diagram 13** Error Statements




gasoline used by one or more crop types. The sum of gasoline and diesel that the user inputs into the facility sheet is then automatically displayed in the "Start" sheet.

Once all the appropriate information is in place for facilities on the "Start" and "Facility" spreadsheets, the user is ready to run a WtoA model. Please see the section "Overview of Running the Model," above, to run a WtoA model.

*Error Statements*

There are three potential types of error that a user can perform in running the WtoA models: 1) Energy mix does not equal 100%, 2) Facility number 20- Others" af/yr is a negative value, and 3) Customer water use is zero (Diagram 13). If a user creates one or more of these types of errors, then pushes the "Update Scenario" button, a dialogue box will inform the user that an error has been encountered and the type of error. All three errors are illustrated in Diagram 13.

Since there are three error statements in this example, the user will need to fix all three. The first is adjusting the red-colored energy mix to equal 100 percent (Mix 4 in Diagram 13). Notice that the example allocates 50% to Natural Gas Power Plant and 100% to Natural Gas Direct Drive, which leads to an impossible total of 150% for Mix 3. The user will need to adjust this energy mix so that the sum equals 100%.

The second problem is regarding Waste Water Collection, Facility "Others." There are two possible sources of this problem. First, the af/yr of water for this category of facilities in the "Start" tab may be too low. In Diagram 13, for example, the total for Waste Water Collection is 0 acre-feet per year, which means that inputting a facility with any positive value (e.g., 1 af/yr) on the facility spreadhsheet will force Facility 20 "Others" in the Wastewater section of the Facility spreadsheet to be less than zero (e.g., -1). The second possible problem is that the user has accidentally keyed in a Facility for Waste Water Collection that is far larger than intended (e.g., 1,000 af/yr rather than 100 af/yr). As mentioned, "Others" is simply the difference between the total af/yr input for the Waste Water Collection category of Facilities (on the "Start" tab) and the sum of facilities 1 to 19 in the Waste Water Collection section of the Facility worksheet.

Third, inputting zero customer use will cause a "divide by zero" error on the summary and output sheets in the column labeled "energy intensity." The models calculate the energy use per unit of water using total customer water use as the denominator (that is, energy intensity is defined as energy use divided by customer water use). Failing to specify positive customer water use not only creates this mathematical problem, but is inconsistent. If the system actually delivered zero water for a year, it wouldn't use any energy, either.

Once these inputs have been checked and corrected, the user will be able to push the "Update Scenario" button without an error message.

## APPENDIX A:
## SOME ENERGY USE INFORMATION

Model users need to develop their own energy use information in most cases. However, some information that may be useful is listed below. We believe the information is correct, and list sources. Nonetheless, the Pacific Institute is not responsible for errors in the information or any problems that might result from use of the model. In particular, default values in the models are provided so that users can have a sense of the relative magnitude of energy use for various facilities, but we do not claim that these default values are average or typical.

**Table A-1:** State Water Project Energy Use

| Delivery Point (outlet) | Energy Use; cumulative (facility) (kilowatt-hours per acre-foot) |
|---|---|
| Banks Pump Station | 296 (296) |
| South Bay Aqueduct | 1,093 (797) |
| Del Valle Reservoir | 1,165 (72) |
| Dos Amigos Pump Station | 434 (138) |
| Buena Vista | 676 (242) |
| Wheeler Ridge | 971 (295) |
| Wind Gap | 1,610 (639) |
| A.D. Edmonston | 3,846 (2,236) |
| Alamo | 3,741 (-105) |
| Pearblossom | 4,444 (703) |
| Mojave Siphon | 4,349 (-95) |
| Devil Canyon Variable | 3,236 (-1,113) |
| Oso | 4,126 (280) |
| W.E. Warne | 3,553 (-573) |
| Castaic | 2,580 (-973) |

Notes: (1) Energy use is per acre-foot at each facility; that is, it accounts for water losses in transmission prior to that facility.
(2) Source: Wilkinson (2000), p. 29
(3) Cumulative energy use in each row is the sum of all facility energy use figures in that row and above.

**Table A-2:** Partial List of Central Valley Project Energy Use

| Delivery Point | Energy Use; cumulative (facility) (kilowatt-hours per acre-foot) |
|---|---|
| Tracy Pump Station (4) | 238 (238) |
| Lift from O'Neal Forebay (4) | 297 (59) |
| Lift to San Luis Reservoir | 597 (300) |
| Hydroelectric generation from releases from the San Luis Reservoir (2) | 387 (-210) |
| Dos Amigos Pump Station (5) | 435-525 (138) |
| Pleasant Valley Pump Station (5) | 673-763 (238) |

Notes: (1) Energy use is per acre-foot at each facility; that is, it accounts for water losses in transmission prior to that facility.
(2) Source: Wilkinson (2000), p. 29
(3) The higher cumulative energy use in each row is the sum of all facility energy use figures in that row and above.
(4) The state water project Banks Pump Station is a parallel path for water en route to the San Luis Reservoir. Its energy use is nearly identical to the CVP pumps.
(5) The lower cumulative energy use is for water that bypasses the San Luis Reservoir.

**Table A-3:** Diesel and Gasoline Fuel per Acre of Cropland Cultivated and Harvested

| Crop | Gallons of diesel fuel used per acre per year (1) | Gallons of gasoline used per acre per year (1) |
|---|---|---|
| Alfalfa | 15.15 | 0.53 |
| Almonds, flood irrigated, San Joaquin (SJ) Valley (2) | 15.81 | 5.25 |
| Almonds, sprinkler irrigated, San Joaquin (SJ) Valley (2) | 11.66 | 9.38 |
| Cotton, Alcala, SJ Valley (2) | 32.31 | 0 |
| Cotton, Pima, SJ Valley (2) | 37.22 | 0 |
| Tomatoes, processing, Sacramento Valley (2) | 84.32 | 1.34 |
| Tomatoes, fresh, SJ Valley (2) | 46.36 | 2.08 |
| Wheat | 16.71 | 0.64 |

Notes: (1) Gallons of gasoline and diesel fuel in cost and returns studies prepared by UC Cooperative Extension, available at www.agecon.ucdavis.edu/outreach/crop/cost.htm
(2) Estimated fuel consumption varies within crop type by location, cultivation practice, species, etc. We've provided three examples to illustrate these types of differences.

**Table A-4:** Other Relevant Data, Including Sources for Default Values

| Type of Facility | Energy Use (equivalent kwh/AF) | Sources |
|---|---|---|
| Generic Imported – Urban Model | 1,000 | Arbitrary but reasonable default value (see Table A-1) |
| Generic Imported – Agricultural Model | 500 | Arbitrary but reasonable default value (see Table A-2) |
| Imported – Colorado River Aqueduct | 2,000 | Wilkinson (2000) |
| Hydroelectricity Production Foregone by Imperial Irrigation District (IID) Transfer of Colorado River Water to San Diego County Water Authority | -110 | Henrik Olstowski, Superintendent of power generation, IID, personal communication. June 2003 |
| Groundwater | 650 | See notes 1 and 2 |
| Reclamation | 350 | See notes 1 and 3 |
| Seawater Desalination | 4,500 | See notes 1 and 4 |
| Brackish Water Desalination | 405; 1,700 | See notes 5 and 6 |
| Ocean-Towed Water Bags, 900 mile round trip | 1,180 | See note 7 |
| Water Treatment | 55 | See notes 1 and 8 |
| Water Distribution | 395 | See note 9 |
| Urban End-Use Categories | Various, see Urban WtoA Model | Wolff, et.al. (2004) |
| Wastewater Treatment | 440 | Burton (1996), weighted average over a range of facility sizes, activated sludge treatment |
| Ten Foot Lift for Flood Irrigation | 30 | See note 10 |
| Low Pressure Sprinklers | 100 | See note 10 |
| Permanent Set Sprinklers | 205 | See note 10 |

Notes: (1) Data from Jeff Stevenson, Water Resources Specialist, San Diego County Water Authority (SDCWA), personal communication. June 2003. (2) Arbitrary but reasonable default value that depends largely on the depth to groundwater. Based on Yuima Municipal Water Authority use at 661 kwh/af; Sweetwater Authority use at 564 kwh/af; and Westlands Water District use at 740 kwh/af. (3) Average of tertiary treatment at three plants in San Diego County: San Elijo (600), Fallbrook #1 (337), and Santee Basin (122). (4) Average of personal communications from John Kiernan of Ionics Corporation for their Trinidad plant (4,800) and Jeff Stephenson of the SDCWA for the proposed Carlsbad plant (4,200). (5) 405 is the Reynolds water treatment plant in San Diego County, which treats brackish groundwater. (6) 1,700 is reported by Wilkinson (2003) for the Chino desalter operated by the Inland Empire Utilities Agency. (7) From tugboat fuel cost data provided by Terry Spragg of Spragg's Bags. Energy expenditure converted to fuel at $1.50 per gallon, then converted to equivalent kwh assuming the fuel was used to produce electricity in a central power plant. (8) Average of three plants in San Diego County: Perdue (41), Escondido-Vista (48), and Levy (68). (9) From Burton (1996) for treatment and distribution combined (450 kwh/af), less default value of 55 kwh/af assumed for treatment. (10) Calculated by the author from California Energy Commission (2001) for irrigation of grapes and almonds.

## APPENDIX B: DOCUMENTATION OF AIR EMISSIONS FACTORS

Air emissions factors were developed using a variety of sources. The factors are based on averages from a limited number of sources and should be both discussed and critiqued for the particular application if the model is used for formal environmental assessments of a water management project (i.e., in an EIR or EIS). When significant uncertainty existed for a particular factor, we used the value that would create the least difference in emissions when shifting energy sources. We felt this type of error was less likely to lead users of the model astray than large but highly uncertain differences in emissions from shifting energy sources. Nonetheless, model users should be aware that differences from shifting sources based on our assumptions may be smaller (or larger) than would occur in particular circumstances.

### The California Grid Mix

The California Grid Mix emissions for reactive organic gases (ROG), carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter less than 10 microns (PM<10) factors are based on 2004 California Air Resources Board (CARB) data provided by Stephanie Kato of CARB in a personal communication. Total organic gases (TOG) and total particulate matter (PM) were estimated as 416% of ROG and 110% of PM<10, respectively, using conversion factors provided by Larry Hunsaker of CARB in a personal communication. The carbon dioxide grid emissions factor was estimated by the authors using data on state and imported fired generation capacity (natural gas, coal, and biomass) in the 2002 California Energy Commission Net System Power Calculation Report (California Energy Commission 2002).

### Natural Gas, Coal, and Oil-Fired Power Plants

Average emissions for natural gas, coal, and oil-fired power plants are also based on data provided by Larry Hunsaker in a personal communication, with one exception. We estimated carbon dioxide emissions for oil based on 35% power plant efficiency. This compares with Hunsaker's assumption of 39% for natural gas power plant efficiency and 25% for coal power plant efficiency. The remainder of the data is for year 2000 in-state electricity production. Since these are the primary sources of emissions from grid electricity, model users can create a mix of these sources (along with hydro/nuclear/solar/wind, which are assumed to have no emissions) that better reflects power provided to them by a local or regional utility or a direct purchase contract, than does the California Grid Mix. Although these data are somewhat dated, we felt it was best to create a model that could accommodate local mixes of electrical sources. Data is easier to update than the model itself.

### Adjustment for All Centrally Produced Electricity

Data for emissions for all centrally generated electricity were provided to us per kilowatt-hour (kwh) generated, not per kwh delivered to customers. According to Mark Layton of the California Energy Commission, the California Energy Commission Demand Analysis office found about 7.5% line losses in a study of 2001 data. Consequently, we divided emissions at central power plants (CA grid mix, natural gas, coal, and oil) by 0.925 so that the emissions factors would reflect emissions per kwh purchased by customers, since this is the data model users will input.

## Direct Drive Pumps

Some water pumps are driven directly by internal combustion engines fueled with natural gas or diesel fuel or gasoline or digester gas, rather than by electric motors powered by generators that run on these fuels. Although electricity is not actually generated at pumping locations where natural gas, diesel fuel, gasoline, or digester gas is used to direct drive water pumps, a manageable model structure and meaningful outputs could not be created without estimating emissions factors in grams per "equivalent" kilowatt-hour. Note that model users are required to input energy used in these ways in units of equivalent kilowatt-hours. A conversion calculator is provided in the models for this purpose.

We obtained data for direct drive natural gas, diesel, and gasoline prime movers from US EPA's "Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition." Tables 3.2-2 and 3.2-3 describe emissions from uncontrolled 4-stroke lean-burn and rich-burn engines, respectively. Table 3.3-1 describes emissions from uncontrolled gasoline and natural gas industrial engines.

## Direct Drive Natural Gas

We used the lower of the two factors from Tables 3.2-2 and 3.2-3 as the source data for our "direct drive natural gas" emissions factors. The higher numbers, which are not consistently from either the lean-burn or rich-burn table, are so high we felt they might lead model users astray. Emissions from direct drive facilities, however, are an important topic for further research. Uncontrolled emissions from such facilities may in fact be higher, at least in some important cases, than we used in the models. We converted emissions data in the various sources cited from units of pounds per million British thermal units (lbs/MMBTUs) into units of grams per equivalent kwh by multiplying by 454 grams per pound, and assuming heat energy is converted to drive shaft energy at 30% efficiency. (Unlike natural gas power plants, which are usually gas turbines, direct drive natural gas pumps are usually driven by internal combustion engines.)

We used emissions data on total organic compounds (TOC) and volatile organic compounds (VOC) as proxies for TOG and ROG emissions. Although these measures are not strictly comparable, they are similar enough that we felt including them in the model was appropriate. Again, it is easier to adjust emissions factors later than it would have been to exclude some energy sources in the model structure now, then redesign it later if better data were available. According to EPA's footnotes to the tables, total particulates (PM) are equal to the sum of filterable and condensable particulates, and PM<10 is the same as PM since all particulates from gas combustion are small. Finally, we assumed that SOx emissions for direct drive natural gas pumps were the same as from average natural gas power plants because the SOx emissions estimates in Tables 3.2-2 and 3.2-3 were much lower than natural gas power plant emissions in California. We found that implausible, and noted that EPA's estimate was a calculation from an assumed sulfur content for natural gas that might be incorrect for California.

## Direct Drive Diesel and Gasoline

Table 3.3-1 of AP-42 provides emissions factors from uncontrolled diesel and gasoline engines in pounds per horsepower-hour. We converted these factors into grams per equivalent kilowatt-hour by multiplying by 0.608, as recommended in a footnote to the table. Again, PM was assumed equal to PM<10 by EPA assumption listed in a footnote, and TOC in engine exhaust was used as a proxy for TOG. We estimated ROG/VOC as a percent of TOC equal to the ratio of ROG to TOG in oil-fired central power plant emissions (about 78%).

## Direct Drive Digestor Gas

Emissions factors for pumps driven directly by engines using digester gas were assumed equal to those from electricity generated with digester gas (below), with one exception. Direct drive does not experience an efficiency loss between shaft power and generator output. We therefore assumed emissions from digester gas used directly were 5% less than from digester gas used to generate electricity.

## Electricity Generated With Digestor Gas

Many wastewater treatment plants generate electricity using digester gas, sometimes blended with natural gas to ensure more even combustion. Resources did not allow a thorough investigation of emissions from these facilities. We did obtain, however, data from the East Bay Municipal Utility District (EBMUD) for the three 1,850 kw internal combustion engine-generators at their wastewater treatment plant. This data was consistent and in our opinion usable for emissions of CO, NOx, and filterable particulates. We used direct drive natural gas emissions factors for the other categories, except carbon dioxide, but adjusted upward to reflect a 5% loss in drive shaft energy as it is converted to kwh in the generators.

Finally, carbon dioxide emissions per kwh are higher for digester gas driven engine-generators than natural gas driven engine-generators because 40% of digester gas (typically) is carbon dioxide that is emitted but does not contribute to production of electricity. The remainder of the digester gas, plus 10% natural gas blended with digester gas, is essentially methane, which creates the same amount of carbon dioxide per kwh generated as would pure natural gas. As a result, the carbon dioxide emissions factor for digester gas is equal to the emissions for direct drive natural gas, adjusted upward to reflect a 5% loss in generation, plus the carbon dioxide that was present in the digester gas to start with. The latter is equal to about 340 grams per kwh based on the digester gas feed rates, density of carbon dioxide at 70 degrees Fahrenheit, and power output reported by EBMUD.

## Energy Used for Crop Cultivation and Harvest

The agricultural model includes emissions from on-farm diesel and gasoline-powered equipment (e.g., tractors) used to cultivate soil and harvest crops, because Wolff, et.al. (2004) found that these types of changes in energy use due to changes in on-farm water management were significant. Including these types of emissions in the agricultural model allows one to estimate impacts from land fallowing or crop shifting that may be associated with water conservation on farms.

Table 3.3-1 in AP-42 also provides emissions factors for gasoline and diesel fuel in units of pounds per million BTUs. Multiplying by 454 and dividing by 0.13 million (130,000) BTUs per gallon of diesel fuel and 0.115 million (115,000) BTUs per gallon of gasoline yields emissions factors per gallon of each of these fuels. As above, PM and PM<10 are assumed equal, TOC in exhaust is used as a proxy for TOG, and ROG/VOC is estimated as 78% of TOC (the ratio of ROG to TOG in oil-fired power plant emissions).

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